TREATISE ON THE

EVAPORATION OF SACCHARINE

CHEMICAL & OTHER LIQUIDS

BY THE

MULTIPLE SYSTEM

IN VACUUM AND OPEN AIR

ALSO THE

CONSTRUCTION AND WORKING OF THE DIFFERENT SYSTEMS

Second Edition

COMPILED BY JAMES FOSTER, M.I.M.E.

WITH 181 DIAGRAMS AND 49 LARGE PLATES

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PREFACE TO SECOND EDITION.

The First Edition of this Treatise having been a great success, I have great pleasure in issuing this the Second Edition, containing new matter which I hope will be of service to both Users and Constructors of Multiple Evaporating Apparatus.

Thanking my readers for the support they have given to the First Edition, which I hope they will extend to this my Second Edition.

JAMES FOSTER.

"Lily Bank," St. Andrew's Drive,
Pollokshields, Glasgow,
March, 1895.

NOTE.

The Metrical System is used generally throughout this Treatise, and to assist my readers in making calculations I have appended several useful French and English Tables.

ABBREVIATIONS.

B. A. D. C.—Bulletin of the Association of Chemists of Sugar and Distillation in France and Colonies, by F. DUPON, PARIS.

B. Z.—Bohmische Zeitschrift, Journal of the Sugar Industry in Bohemia, by DR. NEVOLE.

D. Z. I.—Deutsche Zuckerindustrie: The Sugar Industry in Germany, by DR. STAMMER.

J. d. F. S.—Journal des Fabricants de Sucre; The Sugar Manufacturers' Journal, by B. DUREAU, PARIS.

N. Z.—Neue Zeitschrift: New Journal on the Sugar Industry, by DR. SCHEIBLER, BERLIN.

O.—Organ of the Association of Central Sugar Manufacturers, by DR. KOHLRAUSCH, VIENNA.

Sap.—Sapiski; The Russian Sugar Manufacturers' Journal, by PROFESSOR N. A. BUNGE, KIEV.

S. B.—Sugar in Belgium, by V. BEAUDUIN, BRUSSELS.

S. I.—Sugar Indigene (Industry) Colonial by H. TARDIEU, INGENIEUR, PARIS.

Z.—Zeitschrift; Journal of the Association of Sugar Industry in the German Empire, by DR. STAMMER, BERLIN.

F. S.—Francisco Sachs.

P.—Page.

N.B.—The ciphers indicate the Volume or Number of the Journal or Book.

ERRATUM.

Page 666.—Instead of October 16th, read February 6th.

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TREATISE

ON THE EVAPORATION OF

CHEMICAL LIQUIDS & JUICES,

FROM

BEETROOT, & SUGAR CANE.

INTRODUCTION.

The object of this treatise is to lay before those who are interested in Sugar Machinery and its uses, a work that has long been wanted in the English language, as nearly all books published on this subject are in Foreign languages, with which all Englishmen in this special branch of the Engineering profession are not conversant.

The principal subject of this work will be the construction and working of the Multiple Effet Apparatus, which are used for the evaporation of Sugar Cane, Beetroot, and other Juices, with its history up to the present time.

It is only during the last few years that English Sugar Machinery Makers have given this particular apparatus their attention, and now they turn out these Machines Second to none in the World, as regards workmanship and capacity.

The Author having been connected with the Sugar Cane Industry for upwards of twenty-one years, has had the opportunity of seeing the working and construction of this class of machinery made by nearly all the principal makers in Europe, lithographs of many of these apparatus will be found in this work, also several useful Tables for easy calculation and comparison.

This treatise also contains translations from the works of several eminent continental authors (the names of which are given in the preface) who have made the subject of evaporation their special study, so that they can be relied upon as thoroughly practical.

It is strange, but nevertheless true, that none of the works published in the English language on sugar machinery treat the subject of evaporation by Multiple Effets in detail, viz., the practical description, working or construction, which is of any service to a constructor or user, this may be the reason that those most concerned in this apparatus do not thoroughly understand its true working principles nor do they quite understand that a good working multiple effet evaporating apparatus, is the secret of the economical production and quality of sugar.

After years of experience with the working of Multiple Effets, which would not work up to the guaranteed evaporating capacity, notwithstanding the large heating surface, the author was convinced that these apparatus as usually designed and constructed did not evaporate the quantity of liquid per square foot or metre of heating surface which they should do, and by carefully watching the working it became evident that the vapour generated from the juice, was not able to escape as quickly as it was formed, causing the save-alls to become very hot, in fact the whole apparatus became very hot; in these save-alls water was very often found, formed by the condensation of the vapour, which otherwise ought to have passed without hindrance or interruption in its natural state to the following tubular steam chamber of the vessel in working, and giving out all its useful effect for evaporating the juice in that vessel.

These old fashioned save-alls are good in their way, in catching any juice that may boil or be drawn over with the escaping vapour, but the surface exposed to the open air acts as a surface condenser for the vapour during its passage from one vessel tc the other It will be seen in Foster and Campbell's Patent Multiple Effet that these save-alls are entirely dispensed with, their arrangement giving a free flow or passage to the vapour.

The Author being convinced that the cause of these apparatus not evaporating the guaranteed quantity was as stated above, looked for the best means to remedy this evil, it so happened just about this time that he was asked by the Owners of a large sugar estate in Java if he could increase the evaporating capacity of the Triple Effet, which was guaranteed by the makers to evaporate 225,000 litres or 49,000 gallons in 24 hours, which it would not do, the best days' work being 160,000 litres or 35,200

gallons, and instead of improving after many alterations made by other engineers, it went from bad to worse, until it would only evaporate 100,000 litres or 22,000 gallons in 24 hours. To have made the complete alterations to the author's plans, all the save-alls would have had to be removed, new vapour inlets in the steam chambers to be cut, and all the vessels supplied with new domes, at a cost of too much time and money considering it was only an experiment, so it was decided to let the apparatus stand practically as it originally was, and to bring an extra vapour pipe from the extreme top of the dome on each vessel, down to the front side of the following tubular steam chamber, and at the same angle as the inlet from the save-all.

The outlets for the condensed water from the tubular steam chambers were all found too small, also the condensed water from the second and third steam chambers was drawn off direct by the main air Pump, which naturally took with it a large quantity of unused vapour, thus causing a great loss of useful heat.

These condensed water outlets and pipes were made very much larger, and connected to Foster and Campbell's Patent Automatic Water Receivers, by which no unused vapour can pass away with the condensed water, the condensed water being drawn from the Receivers by a double-acting Pump instead of by the main Air Pump, as the water was required for feeding the Boilers. After these alterations were completed, the Author had the satisfaction after a few days' working, of evaporating 300,000 litres or 66,000 gallons from 8° to 26° Baumé with the greatest ease, and after three months steady work, (*night and day*) without cleaning the tubes in the steam chambers, the evaporating capacity remained the same, and when the bottom covers of the vessels were taken off at the end of the season, it was found that little or no scale had formed on the tubes, this being entirely due to the perfect circulation of the juice, the sediment, &c., not having time to adhere, which is the case when the juice only simmers and scums, and many think it is a sign that the apparatus is working well, being quite the contrary, as when the circulation of the juice is perfect no scum can be seen, the juice rising in the form of a large fountain at work.

At the end of this work will be found a Plate of the

Triple Effet with all the alterations shown in detail. These alterations can be made to any existing Multiple Effets of ordinary construction. In this work will also be found the calculations of M. Paul Horsin Déon necessary to determine the proper dimensions of vapour pipes, heating surface, condenser, and air pump for Multiple Effets for any required capacity.

The Author has designed Triple Effets to these calculations, which have given the greatest satisfaction in every sense of the word.

The following is a detailed description of Foster and Campbell's Patent Multiple Effet.

The three principal points in the evaporation and working of Multiple Effets are as follows :—

1st. To draw off and transmit the heated vapour generated in the first vessel in working to the tubular steam chamber of the next vessel in working as quickly as possible, in order to utilise all the possible heat in the vapour, and to keep the temperature of the vessel in working as low as possible.

2nd. To transmit the heated vapour from vessel to vessel in the most direct line and shortest possible time, in order to reduce the condensation of the vapour in its passage through the connecting pipes to a minimum, thereby obtaining the greatest possible amount of work from the vapour, which by the old arrangement would be to a great extent lost by condensation.

3rd. A proper distribution of the vapour in the tubular steam chambers in order to obtain all the useful heat and a good condensation, and to get rid of the condensed water, in the tubular steam chambers as quickly as possible without taking it with it.

How we have mastered these points and the advantages gained we will now describe, which with the help of the Plates will make the working design very clear.

It will be as well before describing the advantages gained by our Patent Effet, to give a rough outline of the construction and working of Multiple Effets as now used, so that the advantages gained by using our Patent Effet

will be better appreciated by those interested in this class of apparatus.

A Multiple Effet consists of one or more vessels, each being fitted with a vertical tubular steam chamber, which contains a large number of small brass tubes, through which the juice circulates, the steam or vapour being supplied to the interior of the chamber by large pipes, which are connected to these chambers from the top of each vessel.

The tubular steam chamber of the first vessel is supplied by exhaust or direct steam from a receiver, into which all the engines in the fabrick exhaust their steam, and is therefore called an Exhaust Steam Receiver.

The steam chamber of the first vessel receiving the above steam commences the work of evaporating the juice.

The vapour arising from this juice under evaporation in the first vessel, travels through the large pipes mentioned to the tubular steam chamber of the next or following vessel, which gives off the necessary heat for evaporating in that next or following vessel, and so on to the third and following vessels, the vapour arising from the last vessel in working is drawn into a condenser and condensed by injection water, which is drawn off by the main air pump.

The present arrangement of the vapour pipes (as arranged in the Multiple Effets now in use) which convey the vapour from the top of the vessel to the tubular steam chambers, are so arranged or designed that the vapour has to make a zig-zag course, and in nearly all cases these pipes are much too small for the work or purpose they are intended for; these two faults tend to cause a great amount of friction and obstruction to the vapour passing from the top of the vessel to the tubular steam chamber, this friction and obstruction causes a large quantity of the hot vapour to be condensed and lost, which otherwise would be utilised with good effect in the tubular steam chamber for evaporation.

Referring to the drawing or lithograph of our Patent Multiple Effet, it will be readily seen that we have entirely overcome these two great drawbacks, which was our principal object when designing our apparatus.

We will now proceed to describe the three principal points in the evaporation and working of Multiple Effets, which we have embodied in our Patent.

1st.—In order to have the most effect from the vapour arising from the first vessel of Effet, this vapour as it accumulates is lead direct into a combined Save-all and Valve Box, which is connected to the top of the vessel by a short connection of very large area, from which combined Save-all and Valve Box it is lead by two vertical down pipes into the tubular steam chambers. By this arrangement the vapour is drawn off from the top of the vessel immediately it has accumulated, and has an uninterrupted passage to the tubular steam chamber of the next or following vessels down the vertical pipes, thus keeping the temperature in the vessel as low as possible, it being well known that the lower the temperature when boiling in a vacuum the quicker the evaporation.

2nd.—It will at once be seen that by our arrangement of the two vertical down pipes, which are in direct communication with the combined Save-all and Valve Box and the top of the vessel, that the vapour has to travel the shortest possible distance to the tubular steam chamber ; each of these two vertical down pipes have two branches, of a combined area larger than one vertical pipe, these branches on each pipe are connected to the top and bottom of the tubular steam chamber (as shown in lithograph) at an angle of about 45° right and left of the centre line. The connection between the top of the vessels and the combined Save-alls and Valve Box, and the two vertical down pipes being of extra large area, the friction of the vapour in passing through them is reduced to a minimum, also the chances of condensation, as all obstructions to a free passage of the vapour have been removed by the above arrangement. By connecting the branches of the two vertical down pipes to the tubular steam chamber, and also placing these two vertical down pipes at an angle of about 45° right and left of the centre line, we have found by experience from experiments made, that the steam or vapour when entering the tubular steam chambers at the four branches, the greatest amount of effective work is obtained from the steam or vapour, and

we also obtain almost a perfect circulation of the juice in the vessel, which causes rapid evaporation. It will be seen by our readers that all piping communications on our Patent Multiple Effet are in a direct centre line, thus entirely avoiding the zig-zag course which is so objectionable, and a great drawback to the good working of many of these apparatus.

3rd.—The system we have adopted for drawing the condensed water out of the tubular steam chambers, has proved a great success in combination with the above arrangement of vapour pipes, by evaporating a very large quantity of juice per square metre or foot of heating surface. The apparatus for this system consists of one or more receivers or condensed water taps, connected to the tubular steam chambers of the second and following vessels by an arrangement of pipes and cocks, which will be easily understood by referring to the lithograph, these receivers are fitted with a water gauge or sight glass, vacuum gauge and air cock, and internally with an automatic working sleeve valve, through which it is impossible that any steam or vapour can escape along with the condensed water to the pumps which draw the water out of these receivers, as the water inlet is much below the level of the outlet. The condensed water from the tubular steam chambers is drawn into these receivers by a vacuum being formed in them, by a pipe from the top of the receivers to the top of the tubular steam chambers, which also serves to draw back into the tubular steam chamber any vapour or steam that may happen to escape into the receivers with the condensed water, so that it is practically impossible that any useful heat can be lost, (as is the case in nearly all Multiple Effets of the present construction.) When the condensed water rises to a certain level in those receivers, the automatic sleeve valve begins to work by opening the outlet to the auxiliary pumps which are used for drawing out the water, when the water accumulated has been drawn off, the valve immediately closes until there is a

further supply, it will be seen from the lithograph, that it is impossible for the automatic sleeve valve to get out of order or refuse to work, as its construction is simplicity itself. The water outlets of these receivers are also connected to the main air pumps, (in the event of the auxiliary pumps being out of work) with the same effect. The range of pipes and cocks on the tubular steam chambers for the condensed water, are also connected to the air main between the condenser and main air pumps, so that in the event of the receivers not being in work, the cocks in this range can be shut or opened to the air main, which will draw off the condensed water from the tubular steam chambers, which method is still adopted by many makers of Multiple Effets of the present day, this method or system is cheap to make, but causes great loss of useful heat which escapes with the condensed water.

We have not the slightest doubt but that we shall be able to evaporate 1,500 litres juice (from 8 to 27 Baumé) per square metre of heating surface with our Patent Multiple Effet.

Makers and designers of these Multiple apparatus do not seem to have studied thoroughly the work the apparatus was intended to do, if they had, they would have seen at once that the present construction was bad, and to be convinced of this fact, it is only necessary to compare the Lithograph of our Patent Effet with an Effet of the ordinary design by any of the best makers, to see the superiority of ours in simplicity of design and results. Some makers and designers of Multiple Effets seem to have made it a special study to make the vapour pipe connections between the different vessels as long and as zig-zag as possible, and to expose as much pipe surface as possible to the open air, in order to condense as much of the vapour and steam passing through them, instead of making everything connected with the supply of steam or vapour from one vessel to the other as direct and short as possible.

They also loose sight of the fact that every pound of steam or vapour which is condensed, between leaving the vessel working and entering the tubular steam chamber, and also escaping by the old method of drawing off the

condensed water from these chambers direct to the air main, is a loss of a certain amount of useful heat, which could be very profitably used in the tubular steam chamber for evaporation, and when this condensation and escape of steam or vapour is great, the exhaust steam from the different engines will prove insufficient for the evaporation, (which otherwise ought to be more than sufficient, the overplus being used for boiling in the vacuum pan when the serpentines are large enough for working the exhaust steam economically), and direct or fresh steam will have to be added in the exhaust steam receiver, which direct steam means extra expenditure in fuel, which ought not to be if all the useful effect was obtained out of the exhaust steam.

A great many users of Multiple Effets prefer them being made or provided with isolating valves for working any two vessels as a double Effet, in case of accident or for cleaning the tubes of any tubular steam chamber. The arrangement of these in most Multiple Effets retards the free flow or passage of the vapour, by the arrangement of these valves in our Patent Effet this stoppage is entirely removed, as will be seen by the lithograph the pipes and isolating valves over the tops of the different vessels being in one centre line. For our part, we would rather have a plane Multiple Effet, without these isolating valves, which are in the first place, very expensive ; and in the second place, when they are required for use they are generally stuck fast, and cannot be freed without much trouble and delay, whereas any good working fabrick can find time to clean the tubes in the tubular steam chamber if necessary, once in the fourteen days.

By the arrangement in our Patent Effet of the vapour pipe connections to the tubular steam chamber, it causes such a perfect circulation of the juice being treated, that the lime and other matters have not time to settle on the tubes, which is the case in a bad working Effet.

If designers and users of Multiple Effets will carefully read and consider what we have set forth in this article, they will no doubt come to the conclusion that the points on which we have Designed and Patented our Multiple Effet are right.

INDEX TO DRAWINGS AT END.

This invention comprises certain improvements in the construction and arrangement of valves and valve chests and their branches for leading off the steam or vapour from the sugar liquor in the pans of those "triple effets" or multiple evaporating vessels to the steam heating chambers of the other pans and also to the vacuum chests and air pumps; and in the pipe fittings and their valves or taps for conveying the high pressure or live steam to the close steam heating vessels of said pans, and for the drawing off of the condensed vapour therefrom, and water to the pumps without the escape of vapour from the heating chambers; which improvements will add much to the effective action of the steam and vacuum in and consequent boiling or evaporation of the juices of beet root, sugar cane, or other saccharine liquids by these pans; and also effect the isolation and separate working of any one, two, or more of these evaporating pans better than heretofore, and with greater economy of steam heat.

And in order that this invention and the manner of performing or carrying the same into effect or practice may be properly understood, I have hereunto appended explanatory Sheet Drawing, in which the same reference letters are used to indicate corresponding parts in all the Figures where shown, the arrows indicating the direction of the flow of the steam, vapour, and water in the various ducts and pipes. Figure 1, is a sectional plan showing the improvements applied to an arrangement of double or "triple effet" or multiple boiling or evaporating sugar liquor vessels A^1, A^2, A^3, erected each in vertical centre line A, over their tubular and lower steam heating chambers, B^1, B^2, B^3, together with their condensing vacuum chest H, H^1, air pump engine I, and condensed water steam pump L, and the other requisite fittings, all illustrative of the invention. Figure 2, is a sectional side elevation, and Figure 3, an end elevation both corresponding to Figure 1; while Figure 4, is a sectional elevation of one of the lower close steam heating or boiling chambers B^1 of the vacuum pan A^1, looking in the opposite direction to Figure 3; and Figure 5, is a sectional elevation of one of the new or improved water traps K, for drawing off the condensed water of the steam and vapour from the lower

part of the steam heating chambers B[1], B[2], B[3], of the vacuum sugar pans A[1], A[2], A[3].

Referring to these Drawings,—the nature and novelty of these improvements and mode and means of putting the same into practice, consist all as follows:—First, in leading the live steam from any ordinary steam boiler, by transverse pipes *b*, (or other equivalent) by two or more branches *b*[1], *b*[2], (or it might be by an outer casing with two or more inlets) at an angle within 160 degrees, towards the centre A of the close steam heating tubular chambers B[1], B[2], B[3], below the first and each successive sugar boiling vessel A[1], A[2], A[3], of the whole set, as say at from 20 or 30 degrees up to 90 degrees of an angle on either side, to the right or left of the centre line 1—1 through the whole set of vessels. These transverse steam pipes *b* are each fitted with a controlling valve *c*, from one main longitudinal pipe C, from the steam boiler, and may isolate any one of these pipes *b*, *b*, *b*; or it might be other valves from other steam pipes, as that *c*[1], of the exhaust steam pipe from the engine of the sugar work, or live steam from a different boiler or supply. These transverse steam pipes *b*, between each pair of the lower steam heating chambers B[1], B[2], and B[2], B[3], have one or preferably two tall vertical pipes *b*[3], leading up to and within transverse and longitudinal save-all trap valve chambers D above and between each pair of boilers A[1], A[2], and A[2], A[3]. The close covers of these chambers D are fitted with screwed-down valves D[1], on screw spindles passing out through stuffing boxes over the top end of each pipe *b*[3], so as to shut these pipes off and isolate the succeeding boiler A[2], from being heated by the steam or vapour evaporated in the first or preceding boiler A[1]. Over the second boiler A[2], and each succeeding boiler, would be fitted an isolating valve chest E, with double ports *f*, *f*[1], and chambers E E[1] over each other, and a double isolating faced valve F, in the lower division E[1] on one central spindle F[1], passed out through a stuffing box in the cover of the chamber E above, so as to shut the port *f*[1], and isolate the boiler A[2], or shut the port *f*, in the central division and isolate the preceding boiler A[1]. These isolating double valve chambers D and E, E[1], are all connected in line by branches D[2], E[2], as seen in Figures 1 and 2, so as to lead by one branch and pipe G from the valve chamber E[1] of the last boiler A[3], of the

set direct to the save-all and vacuum chamber H, H^1, fitted over and round the upper part of the usual vertical injection stand pipe and condenser H^1, leading to the air pump engine I; or otherwise an intermediate save-all chamber G^1, with baffle plate *g* may be fitted in the pipe G.

These save-all chambers D D, and G^1 or H have each pipes *d* connected from their lowest part leading to the top of their adjacent boiler A^1, A^2, A^3, to conduct all liquor trapped in them back into their respective boilers. The stand valve pipes b^3, are connected by branches b^4, above those b^1, b^2, at their lower ends, leading into the upper part of the close tubular steam heating vessels B^2, B^3, to lead in the steam or vapour boiled off from the one boiler A^1 or A^2, at an angle towards the centre A, of the steam heating vessels B^2, B^3, in the same manner as that described in reference to the branch b^1, b^2, of the steam pipes *b* below them.

A further improvement consists in the fitting of an arrangement of a set of longitudinal pipes J, J, with separate branches and controlling three way taps or cocks J^2, *leading from the lower parts of the steam heating* chambers B^1, B^2, B^3, to draw off the condensed water from these chambers by the branch J^1 to the pipe I^1 of the condenser H^1, and the branches J^3, and cocks J^4 to the different condensed water discharge traps K connected by pipes and three-way cocks K^1, K^2, to the suction pipe or valve chamber I^1 of the air pump I, or to the auxiliary pumps L. Small pipes *j*, *j*, are also lead from an upper part of the steam heating chambers B^2, B^3, to the upper part of the water traps K, and to the pipes I^1 of the condenser, and are fitted with controlling taps or cocks j^1, to regulate the pressure in the traps, above the water to be the same as that in the steam heating chambers B^2, B^3, and in the condenser H^1, so as to allow the water to be drawn off from these vessels B^2, B^3, or K, by the pipes K^1 or J^1, to the air pump I or to the auxiliary pumps L.

Pipes and cocks *i*, i^1, are lead from the top part of the steam heating tubular *chambers* B^2, B^3, *of each boiler* and are connected directly to the pipe I^1 leading between the condenser H^1 and the air pump I to draw off all gases and air which accumulate in these chambers B^2, B^3, and enable these chambers to be worked by steam or vapour below the pressure of the atmosphere. The water drawing

off pipes J^3, and trap K, are all arranged below the level of the lowest water receiving parts of the steam heating chambers B^1, B^2, B^3, so as to draw off the condensed water from these. The water from the steam condensed from all, or any particular steam heating vessel, is so lead into one or more water receivers or steam and water traps K, preferably of the improved construction, shown in Figure 5, with an automatic arrangement of ball float *k*, having attached to its under part a sleeve socket k^1 working over a short stand valve seat k^2, over the outlet pipe K^1, with lateral side ports k^3, in both, below the water level W, by which means it is impossible that there can be any loss of steam or vapour being drawn off with the water (from condensed steam from any of the vessels B^1, B^2, B^3) by the auxiliary pumps L. or by the air pump I, of the vacuum main condenser H^1, if there are no auxiliary pumps, or if these are out of order. By this arrangement the openings k^3, of the automatic exit valve k^1 of the trap K are always below the admission level of the water by the pipe J^3, so that the float *k* falls with the level of the water and shuts these outlet openings, always retaining some water in the bottom of the trap and prevents steam or vapour being extracted by the vacuum or auxiliary pipes K^1, but will draw off all the water as it collects, by the rising of the float *k*, and maintain the vacuum in the trap K. The receivers or traps K are so connected at the top by pipes and cocks *j*, j^1, to the upper part of the steam heating chambers of the vessels B^2, B^3, and to the vacuum space in main condenser pipe I^1, or pump I, so that the water can either fall by its own gravitation into the receivers K (which are placed lower than steam chambers B, B^1, of the evaporating vessels) and then be either drawn off by the auxiliary pump L or by the main condenser pump I, through the pipes K^1, as regulated by the cocks K^2. Each drawing off trap K, would preferably be fitted with a glass or other water gauge outside.

The juice is supplied to each vacuum pan or vessel A^1, A^2, A^3, much in a usual manner by a pipe and cock *a* outside, down through a new central circulating pipe a^1 either from the source of supply to the first vessel A^1, or through the pipe a^2, to any of the other vessels A^2, A^3, as seen particularly in Figures 2 and 4. The liquor is drawn off from the lower part B, of each vessel A^1, A^2, A^3, below the heating vessels B^1, B^2, B^3, through the dis-

charge cock and pipe a^3, leading to the horizontal pipe a^2, which is fitted with cocks a^4, for that purpose or for supplying it from any one vessel into the other.

We obtain by these improvements the evaporation of a much greater per-centage of juice, than by the present system of evaporation in double, triple, or other multiple effets, with the same amount of heating surface. The live and evaporated steam is so introduced by these improvements to the first, second, third, or more vessels B^1, B^2, B^3, by the pipes b^3, and branches b^1, b^2, and those b^4, b^4, at two or more places in each vessel; at such angles as to obtain the greatest heating effect on the tubes within the vessels B^1, B^2, B^3, and give the most efficient circulation of juice being treated. From the first vessel A^1, the steam or vapour arising from the juice or liquid being treated passes into the first save-all valve chamber D (having an arrangement of valves D^1, D^1, for isolating the steam heating chamber B^2, of the second vessel A^2, if required) and may go to the tubular steam heating chamber B^2 of the second boiler A^2, by one or two pipes b^3, b^3, when the valves D^1, are opened and the isolating valve F, closes the port f to be distributed to two or more branches b^1, b^2, b^4, b^4, at the said angles, either by using the branches b^1, b^2, b^4, b^4, or it might be by a casing with two or more corresponding inlets.

The steam arising from the juice or liquid being evaporated in all the vessels is lead off through the same arrangement of save-alls, pipes and valves as from first vessel to second vessel. By this system the steam or vapour passing from one vessel (A to A^3) to another has the freeest possible channel way to all the heating vessels B^1 to B^3, and to the condenser H^1, being connected with branches D^2, E^2, and valve chests D and E E^1, as seen particularly in Figures 1 and 2, in a straight centre line between the ordinary isolating valves D^1, E, and top of vessels, thus reducing friction and condensation to a minimum.

EXTRACTS

FROM

M. PAUL HORSIN DÉON'S

TREATISE

ON

SUGAR MAKING & EVAPORATION,

1882.

EVAPORATING AND BOILING BY TRIPLE AND MULTIPLE EFFETS.

At the present day the evaporation of cane and beet root juices is exclusively done in a vacuum by means of Multiple Effets Apparatus, invented by Mr. Rillieux in 1830. In the notes at the end of this work, special attention is given to the history and calculations of these apparatus, here will only be given the general principles of their working figures, Plate II.

The working of these apparatus is based on the low temperature at which liquid boils, under a pressure less than the atmosphere, the following law is given by Dalton :—

The elastical force of the vapour during the boiling, is equal to the external pressure, on this principle the enormous power of the engine is based, also the considerable evaporating power of the Multiple Effet Apparatus. If the pressure on the surface of the liquid is varied by increasing the atmospheric pressure by confining the steam or vapour produced by the heat in a small space, the same as in a steam boiler, or by reducing the pressure by making the vacuum in the vessel, the expansive force of the vapour for boiling will vary to a high degree. Water will boil at 182° under a pressure of 10 atmospheres, and at 66° at a quarter of an atmosphere. It will be understood that in closed vessels, the water boiling at 66°

will easily produce vapour of a low temperatnre, and that less steam or vapour will be required if it is intended to bring the water up to a 100°.

Gay Lussac has compiled a table indicating the expansion in heights of mercury of the steam or vapour from the water, and the corresponding temperatures for the pressures below those of the atmosphere. Regnault has modified and revised this table, which will be found at the end of this work.

These principles being known, it will now be seen how these Multiple Effet Apparatus are worked, at the same time it will be best to describe the working of Mr. Rillieux's original apparatus.

In 1851 and 1852 Mr. B. Durand published a report of these apparatus, which he had worked himself in Louisiana, from which the following extract is taken.

The apparatus Rillieux is based on the employment of the latent heat contained in the vapour which arises from the juices of the cane or beet root, for the concentration and boiling in a vacuum the syrup produced from the same juices, thus using a considerable quantity of heat, which would otherwise be lost, if open pans were used, and also if used in the apparatus Degrand under the atmospheric pressure.

The Rillieux apparatus is composed of three or four cylindrical vessels, made of iron plates, 10 ft. long × 3 ft. 6ins. diameter, made parallel and supported by cast-iron columns, which are placed at each end, in the interior of which the steam or vapour circulates, and passes from one vessel to the other, by means of a system of valves and pipes, each vessel is provided with a dome of a similar appearance to that on a locomotive boiler, see Plate 2 at end.

A.B., C.D., (80 and 81) is the description of the apparatus with four vessels.

The juice when leaving the filters runs into an iron tank, from where it is supplied to the first vessel A by a pump and pipe, which is connected to the back end of the vessel. This pipe is provided with a cock or valve for regulating the supply, which is opened or shut as required by the attendant, at the front end of the same vessel there is another pipe, which conveys the juice to the back end of second vessel B, on that pipe and under the second vessel

is also a cock or valve for regulating the juice supply; a second pipe A conveys the juice which has attained a density of 15° Baumé into the back end of the vessel C. There is also another pipe provided with a cock or valve *for regulating the supply from the vessel C to a pump* which draws off the syrup into two vessels, when it has attained a density of 28° Baumé. These vessels are fitted and heated with serpentines, and the syrup brought to the boiling point and carefully skimmed, from these two vessels it is passed for a second time through the Animal Charcoal Filters, from where it runs into a special reservoir *to supply the fourth vessel D which is the vessel for* boiling to grain.

Now will be described the course of the steam or vapour:—

The exhaust steam from the engines is supplied to the first vessel through the column E, below this is a pipe, which carries the steam direct from the steam boilers, when necessary this pipe is also fitted with a stop-valve connecting the two pipes for supplying the exhaust steam pipe with direct steam, in case the former is not sufficient for the concentration of the juice.

The steam or vapour which arises from the juice under evaporation in the first vessel A, passes down the pipe H, and the column *l*, and then into the cast-iron case K. A portion of this steam or vapour rises into the column E to supply the second vessel B. Another portion passes through the horizontal pipe M M, then into the column l^{111} to supply the vessel D, for boiling to grain, the vapour which arises from the second vessel B, passes into the column L^1, and the case K^1, and ascends the column l^2, to cause the vessel *c* to boil. The vapours from C and D passing through the columns l^2 and l^1 are reunited in a horizontal pipe and return to the condenser, where the steam or vapour is condensed by the ordinary means, viz., injection water.

The vacuum is maintained by means of an air pump of large *capacity*.

The condensed water from the vessel A, is lead by means of the pipe *c*, to a cast-iron tank on the foundation of the engine, from there it is pumped into the boilers, the condensed water of the second, third, and fourth vessel, which is the condensed vapour of the juice, is drawn

off by a special pipe, provided with branches and valves, and connected to a small air pump which delivers it into a reservoir, from where it is drawn for different purposes.

It will be seen after this description that the Rillieux apparatus with four vessels is a Triple Effet apparatus for evaporation, the fourth vessel serving for boiling to grain, and is heated by a portion of the steam or vapour of the first vessel, which is thus boiling to grain with a double effet. Then there is the description of the Rillieux apparatus with three vessels which is a double effet apparatus for evaporation and double effet for boiling to grain, this is the same apparatus as the preceding, in which for instance, the second vessel should have been omitted.

The following observations have been made :—It may happen that the supply of juice is insufficient, or that the evaporation is very quick, in which case the working of the two first vessels must be stopped, shutting all valves and suppressing the steam, at the same time the advantage of the exhaust steam from the engines must not be lost, but supplied direct to the vessel boiling to grain, which particularly accelerates the evaporation of the syrup.

The first vessel of the Rillieux apparatus may be considered as the steam boiler for the two others, and in consequence the pressure will be variable, and according to the density of the juice, or the exhaust steam or vapour, there is sometimes a pressure of $\frac{1}{4}$ or $\frac{1}{5}$ of an atmosphere in the first vessel, and sometimes a vacuum to avoid the pressure being too great, the first vessel is provided with a safety valve.

The Rillieux apparatus is well adapted for boiling to grain, and the results obtained are most remarkable, it is with this apparatus that at once can be obtained that fine grain sugar, in large brilliant crystals which is so much admired by every one who visits the sugar factories of Louisiana.

The whole Rillieux apparatus is made of wrought iron, which is of no great objection, provided that it works continually, and is not given time to oxydize; each vessel is provided with a butter or air cock for the supply of air when it is required.

From this description it will be seen, that the exhaust steam from the engines heats the first vessel of the

Multiple Effet apparatus, and the steam or vapour formed in the first vessel, heats the second; the second the third, and also that the vacuum is obtained or produced in the third vessel by the condensation of the steam or vapour by injection water, and under the influence of that vacuum the liquid begins to boil at a low temperature, at the same time taking the necessary heat from the steam or vapour of the preceding vessel which is also condensed, causing a relative vacuum in the second vessel, which will produce a vacuum in the first vessel; thus when one vessel is heated, it is sufficient to boil the three, so that theoretically, one kilo of steam or vapour is sufficient to evaporate three kilos of water, therefore the apparatus is named a Triple Effet. It will also be noticed that in Rillieux's apparatus, a portion of the steam or vapour of the first vessel is used in the vessel for boiling to grain, which then works as a double Effet.

The boiling to grain with a Multiple Effet has not been applied in Europe in consequence of causes which will be hereafter explained, and which is a great detriment to the sugar manufacture.

The working principle of the Rillieux apparatus must never be changed, as it has never been improved upon, on the contrary these new apparatus have never given the same satisfaction as those of Rillieux.

Multiple Effet apparatus can be constructed with four or five vessels, and even more. In a beet root sugar factory the Quintuple Effet apparatus should only be used with a Triple Effet for boiling to grain, so as to obtain the maximum economy of fuel.

As the Triple Effet is the most used at present, attention will only be given to these, the form of the vessels varies with the constructors, the two principal forms being horizontal and vertical, which can be heated by tubes or serpentines. It is a greater advantage to heat the apparatus for evaporation by means of serpentines than by the ordinary tubes, as the condensation on the tubes is only 3 kilos of steam or vapour per square metre per second, and per degree of reduction when the juice circulates through the tubes. With serpentines the condensation is 8 and even 9 kilos in which the steam or vapour circulates, and are surrounded by the juice. It is more advantageous to circulate the steam or vapour through the pipes than

the juice. Thus there will be two cases, viz.—1st, the horizontal vessels of the Rillieux apparatus fitted with serpentines for boiling to grain, and 2nd, the vertical vessels for ordinary evaporation with serpentines of Mr. Le Banneur. Showing that the horizontal vessels are considered better than the vertical.

The juice of beet root and sugar cane is liable to cause considerable incrustation in the tubes, so that apparatus were required that were easy to clean.

Mr. Rillieux gave a German named Bramé Andrea, rough sketches of his apparatus, who sent them to Europe (which caused the adoption of these apparatus there) without knowing how to work them, these sketches were for an apparatus with vertical vessels, similar to those which are now constructed as being the easiest to clean, there is no doubt but these rough sketches served Cail & Co. for the construction of their first vertical double Effet, (Fig. 82), which were double Effets for evaporation and boiling to grain, and constructed exactly according to the principles of the horizontal apparatus of Mr. Rillieux. (The same letters in the Rillieux apparatus indicate the pipes for the same use) A and B being the double Effet for evaporation, A and C the double Effet for boiling to grain, M the condenser common to the vessels B and C. only Cail & Co. did not understand that C was the vessel for boiling to grain, and made it a vessel for ordinary evaporation, from this cause the tradition of the boiling to grain with a double Effet was lost.

The Germans, however, kept to the horizontal type of vessels, and looking for the easiest means to clean the tubes, they commenced by substituting the turned and screwed pipes in the tube-plates, with brass nuts with india-rubber rings at the ends, then they finished by grouping the tubes in threes, fours, and even sixes, (Figs. 83 and 84, Plate II.) so that all the pipe ends were fastened at once by a small bolt.

In this Effet the plate B is made so that it encloses perfectly the india-rubber rings A of the six pipes or tubes, (as constructed by Buckau) by this arrangement much time is saved in taking the pipes or tubes out and putting them in for cleaning purposes, and the joints are tighter, every constructor has his own system of jointing. Whatever system is adopted, the method of supplying the juice, extracting the syrup, the difference in the vacuum,

and the internal temperature are sensibly the same. The vacuum is sometimes indicated by a column of mercury used like a barometer, or by a quadrant gauge. These gauges show the difference between the atmospheric pressure (76 c/m or 28 inches) and that of the interior of the vessel. If the vacuum was perfect, the vacuum gauge would indicate the daily atmospheric pressure, exactly the same as an ordinary barometer. If the internal pressure is the same as that of the atmosphere the vacuum gauge will show 0°. The expansion of the vapour or steam of water being 76 c/m at 100° which will be reduced to 0° if *the temperature of the steam or vapour diminishes*, whilst the vapour is at 100° the vacuum gauge will show 0°, and increases with the fall of the temperature. Thus, the expansion of the steam or vapour in the apparatus will be represented by the number obtained when 76 c/m is reduced to that which is shown by the vacuum gauge. To each expansion of the steam or vapour corresponds a temperature determined by the boiling of water, the vacuum gauge shows also the temperature at which water will boil under the same pressure. Henceforth we will indicate the expansion of the steam or vapour by its number on the vacuum gauge, as we usually express ourselves by saying that there are so many degrees of vacuum in the apparatus, a bad expression, but one which we are obliged to use in order to make ourselves understood in the factories. The boiling temperature of the juice is properly not that of its steam or vapour, as the more the juice is concentrated the higher will be the boiling point, and the temperature of its vapour at the atmospheric pressure will always be 100°, thus a juice containing 20% of sugar boils at 100°·5, whilst a juice containing 50% of sugar boils at about 102°·25, and at the point of forming grain it varies from 112° to 114° as indicated in the diagram attached to this work. The difference between the boiling point of the liquid, and the temperature of the vapour being constant, and knowing the density of the liquid and the expansion of the vapour, we have by means of this diagram the boiling temperature of the liquid, at the same time it will be found much easier to use a thermometer in the vessels. There are thermometers constructed, which show at the same time the density of the liquid which would boil at the corresponding temperature, so that from the indication of the vacuum gauge, can be deduced the density of the liquid in the vessel without taking proofs. The

vertical vessels of the Triple Effets which are generally constructed in Europe (Fig. 87) are composed of three principal parts. A cylindrical portion of cast or plate iron placed vertically, and resting by a flange L on four pieces of plank *solidly fixed ; this calendar* or chamber is closed at both ends by two brass plates, perforated with holes and bound together by several stay bolts. The diameter of the tube holes in the top plate is *50* millimetres, and those in the bottom plate 46 millimetres. In these holes are fitted brass plated tubes 1·50 metres long, these are forced or driven into the cover plates from the top, and are attached to the upper plate by a patent apparatus for the purpose which we will describe later on. This calendar has fitted to it, a little above the floor, a strong pipe C, on which a cock gives access to the heating vapours which circulate round the tubes. The condensed water from the first tubular steam chamber escapes by a pipe which communicates with the condensed water tank, which water is used for feeding the boilers, the condensed water which accumulates in the tubular steam chambers of the second and third vessels is drawn out by a pump specially for this purpose, and can also be drawn off by the pipes E and F, which are fitted to the centre of the tube plate. There is also fitted to the underside of the top tube plate of these two vessels, a small pipe for drawing off the ammoniacal gases which escape from the juice by evaporation and accumulate under this plate, and prevent the steam or vapour from circulating and heating that part of the tubes, thereby loosing a great amount of useful heating surface. These small pipes are attached on any convenient vacuum space to form a vacuum for drawing off these gases. This ammoniacal gas being in continual contact with the brass tubes of the steam chamber, would cause corrosion and soon eat them away, to prevent this is the reason why these tubes are tinned on the outside, and even then they wear very rapidly. The Fives Lille Co., instead of tinning the tubes as above, have taken out three of the small heating tubes, and inserted in the holes in the top tube plate, three vertical pipes, which unite in one at H in the inside of the vessel and lead through the side to the exterior, by which system the ammoniacal gases are taken off better; even this is not sufficient, and Mr. Rillieux has applied more of these pipes to the top of the top tube plate, and which are united or attached to an interior receiver, from which the gases are drawn off.

The bottom of the tubular steam chamber is closed by a cast iron cover M (Fig. 87) and provided with a manhole N, and jointed with red lead and bolted on the top of the tubular steam chamber, there is a calendar or belt provided with a dome and vertical sight glasses, so as the working of the liquid and its height can be seen in the vessel, the back of which is also a sight glass, provided with a lamp reflecting to the inside of the vessel. The front side of this calendar or belt is also provided with test cocks and glass for testing the density of the juice, air cocks, &c., and the back part with a manhole, for permitting the entrance of the workmen for repairs or cleaning the tubular steam chamber.

The juice from the first vessel can be supplied to the second, and that of the second to the third, by a range of piping connected to the bottom covers of the vessels with the top calendar or belt above the top tube plate.

During the evaporation there is a violent and very irregular eddy in all the tubes; to facilitate the circulation there is placed in the centre of the tube plate a tube of larger diameter P, through which the down current is formed, the heating power of this large tube being less than the small ones.

There was another difficulty, which was that the steam or vapour entering the tubular steam chamber, did not circulate and condense regularly on all the tubes, and to improve this, a belt was formed around the tubes, cast on the outer casing of the tubular steam chamber, in order to make the force of the steam or vapour follow a zig-zag course, or in a circle round the outside of the tubes.

The Fives Lille Co. constructed their apparatus differently, distributing the steam or vapour round the tubes the chamber for which has a ball form, and between the outer case and the tubes is placed a second case B, made of perforated sheet iron, compelling the steam or vapour which enters by the supply pipe to be distributed the full height of the steam chamber so as to produce a circumferential distribution perfectly uniform, going from the periphery to the centre of the group of tubes, so that the steam or vapour first meets the part containing the most tubes, and the condensation finishes in the part with the least number of tubes and on the large central tube, at the bottom of which the small pump for drawing off the condensed water is attached. (Plate II.)

The vapour produced in the vessel working escapes into P by a connecting pipe of large diameter, made of cast or sheet iron, where it is condensed in the tubular steam chamber of the next vessel, between the two vessels is placed a save-all for separating or preventing any juice that boils over continuing its course with the vapour from which it derives its name, the inside is fitted with a vertical pipe down which the vapour passes to the next tubular steam chamber, the juice boiling over falling between this vertical pipe and the outer casing. For some years these were placed on top of the vessel in the form of a cylinder or large dome, and fitted with isolating valves, they were made *1·50* metres high and *95* centimetres diameter. The general system of all these save-alls consists of the valves (isolating) being placed on the top, and to convey the steam or vapour to the tubular steam chamber by the vertical pipe as mentioned, the outer casing having a bell-formed top, into which casing the juice boiling over falls, and is drawn off as required.

The vapour on leaving the last vessel enters a condenser, which is also constructed as described above as a save-all, the vapour being condensed in the internal vertical pipe which forms the condenser. The condensation of the vapour is effected by cold injection water, and this condensation forms the vacuum in the last vessel. the condensed water from the vapour and the injection water is drawn away by a pump of large capacity. If the apparatus is of large dimensions, to avoid the use of these costly large pumps it was thought cheaper to use a simpler system, which was by using the barometrical column produced by a column of water of more than *10* metres high, it being known that the atmospheric pressure balances a column of mercury of *0·76* metres, or a column of water *10·33* metres high in the tube, that is to say, the top of the last vessel communicating with a tube or pipe *12* metres high, the bottom end of which is placed in a tank of water. If a perfect vacuum is formed in the vessel the water in the tube or pipe will rise to a height of *10·33* metres, and if lower the vacuum is less. The construction of the apparatus is as follows :—

Leaving the save-all the vapour passes through the connecting pipe A, joins the top of a tube or pipe which is *11* or *12* metres high (Fig. 92), the top of this

barometric tube or pipe is expanded, and contains a perforated pipe BB, through which the injection water is supplied for the condensation of the vapour. The bottom end of this barometric tube or pipe is immersed in a tank of water C, as the vacuum is formed the water in the tank rises in the tube or pipe to a certain height, and the injection water and the condensed water fall on the top of the liquid column, the level of which remains constant. The overplus of water returning or falling into the tank at the bottom of the tube or pipe, so that that there is a continual stream of water passing through this tube or pipe into the tank which is fitted with an over-flow pipe placed high enough to keep the end of the barometric tube or pipe always under water, by this system no pump is required, the stream of water flowing of itself. In order to make this barometric system work, it is necessary to form a vacuum in it, by means of a small pump of which the pipe D is on the top of the apparatus, and so fitted that its working does not draw off either vapour or liquid; it works continually in order to draw off the uncondensable gases by which a more perfect vacuum is formed. This apparatus is much used in Germany, where it has given good results, it economises working power, costs less than pumps, and gives very little trouble, as it does not easily get out of order or require repairing; at the same time it is necessary to take the following into consideration, viz.:—In order to raise the water to the height of 12 or 15 metres, a pump of large capacity is required, also, always a small air pump, so that this barometric condenser must have *two* pumps which is generally more costly than having *one* air pump as generally used. This barometric condenser is only used in particular cases, and not generally.

WORKING THE TRIPLE EFFET.

When the Triple Effet is erected and everything found perfectly air-tight, the first thing necessary is to form a vacuum by means of the air pump, when all the pipes discharging the condensed water must be closed if they are provided with cocks or valves, and the ammonia gas cocks must be opened, so that all the vessels of the Effet show the same amount of vacuum, at the same time drawing off the air which is in each vessel, which air would otherwise prevent the proper circulation of the vapour.

To be certain that all is perfectly air-tight, the usual way is to try all the joints with a lighted candle, if there is no leakage the vacuum remains stationary, after which juice is supplied by opening the supply cock or valve, when the vessels are each filled to the proper height. Steam is then supplied by opening the steam valve very slowly, and the juice being hot the evaporation commences, and precautions must be taken not to allow the formation of scum. When the steam or vapour circulates well in the first tubular steam chamber, the normal vacuum is soon formed in all the vessels. The juice supply to the Triple Effet is regulated by opening each supply cock or valve on each vessel sufficient to keep up the supply equal to the amount evaporated, and it is soon seen when the third vessel is full of syrup of the required density, at which point the tapping off is commenced, this can be done in two ways, that is to say, by a pump or montjus, by either system it is recommended that the syrup should be drawn off steadily and without stoppage, by so doing the Triple Effet does the most work. Nothing is more simple than the pump, as it only requires its cocks or valves to be regulated for drawing off the proper quantity of syrup so that the density of the same in the vessel will be constant. As far as the montjus is concerned it is equally easy to supply it continually, as it is placed lower than the third vessel, so that the syrup flows into it by its own gravity, the top of the montjus is connected by a pipe and cock to the top of the third vessel or other convenient vacuum space so that the same vacuum will be formed equally in that vessel and the montjus, so that it is quite easy to regulate the flow of the syrup continually, the only objection to a montjus is that it is difficult to clean. In order to empty the Triple Effet the liquid remaining in each vessel must pass through the montjus by a special range of pipes and cocks connected to each vessel for that purpose.

CONDITIONS OF BOILING TO GRAIN.

There are many ways of boiling to grain, according to the steam or vapour used, whether direct or exhaust steam, and according to the pressure at which it is admitted into the serpentines. The first closed vessels

were constructed by Howard, and only admitted the use of low pressure steam; in the apparatus of Rillieux, which preceded those with high calendars or belts, and which were of the horizontal type the same as a locomotive boiler, the boiling was done by a double Effet, and with a still lower pressure than adopted by Howard.

It is evident that by boiling with steam or vapour at a low pressure, the heat of which is less than of steam at 5 atmospheres as used at the present day, the vacuum in the vessel must be higher, so that the difference between the temperature of the steam or vapour used and that of the boiling liquid is the same in the two cases; this is what distinguishes the two systems of boiling to grain.

If the old system of boiling with a low pressure is adopted, a system which has a great advantage over the first, by not forming caramel, during the whole time of boiling there must be a maximum of vacuum, excepting when the first syrup which has been supplied is being formed into grain, the rest of the boiling is a mere knack which the sugar boiler soon finds out. This method of working is very simple, and it has often been asked why it has been abandoned.

When it is required to form large grains by using high pressure steam, the advice contained in the text of Leluy can be followed, which is :—

When the vacuum is at 15 or 16 inches, the syrup supply valve or cock is opened 4 or 5 turns, and the supply continued until the bottom serpentine is covered to a height of 15 or 20 c/m. Then commences the boiling by opening the steam stop valve *two* turns, at the same time the general supply pipe which is placed at the end of the steam receiver must be opened full, the pressure in the pipe can be regulated by the steam gauge which must not be more than 6/10 or 8/10 of an atmosphere. During 4/5 of the time of working, the vacuum must not be higher than 17 or 18 inches and the temperature 75°. It is only when the boiling is irregular that there need be any anxiety, after this the steam is increased in pressure to 1½ or 2 atmospheres, this temperature being sufficient for the rest of the boiling. Attention must be given to the steam gauge for the pressure of steam in the serpentines, and the amount of vacuum in the vessel, which should be inversely proportional to the degree of concentration of the syrup, so that the

larger quantity of water the syrup contains the lower will the vacuum and pressure be and *vice versâ*. A constant balance must be maintained during the time of the first phase, there must be a continual supply of juice or successive charges, after *1½* or *2* hours the evaporation reaches its limit in vacuum pans having *100* to *150* hectolitres capacity, and longer for larger pans. The syrup then presents a new form, the vapour bubbles being much more difficult to destroy, as they are cooled by their slow ascension through the mass and come to the surface in the form of thin syrup, which form small soapy bubbles where they remain sometime before they burst, after which the steam must be raised exactly to *3* atmospheres and the vacuum to *18* inches.

1st. The point at which grain is formed is *42½°* to *43°* Beaumé. The following syrup having a density of *1·1476* or *18°* Beaumé to *20* centigrade gives as follows :—

Sugar	32·62	becomes	Sugar	81·85
Salts	1·05	,,	Salts	2·94
Organic Matters	1·50	,,	Organic Matters	4·81
Water	64·75	,,	Water	10·40
	100·00			100·00

INDIRECT PROOFS. STEAM GAUGES.

If these are well looked to at the commencement, and the initial steam pressure not changed, the vacuum gauge should indicate *19* inches, and the pressure of steam should be from *3½* to *4* atmospheres.

Boilings that are brought up to a high density rise and fall very heavily and settle horizontally along the sight glass, having the same appearance as the circles formed in a bottle when the liquid is shaken or agitated.

The particles or drops of syrup which contain grain, and which are thrown against the sight glasses by the boiling at the top of the mass are very dense, compact, half spheroidical, as drops of fat entirely different from the original liquid, and stick as a crystal along the sight glasses, from where they descend slowly, their passage is recognised by a thin strip of syrup which is of a lighter colour than the mass of the drop or particle, these are different from the syrup bubbles which accumulate at

the same time on the sight glasses, and do not contain air, being very thin, and formed only of syrup which is more coloured in the centre than at the outside. The scum is very voluminous which causes an irregular covering sometimes on the small mass or particles of syrup giving them the appearance of swelling resembling the other particles or drops, these descend slowly on the sight glasses in thick stripes.

DIRECT PROOFS. WITH THE PROOF STICK.

The proof must be taken as small as possible, and the fingers must never be moist. The syrup proofs are presented in the following order until the point of forming grain is reached :—

1st Proof. (Steam at 3 atmospheres, 2/10 or 18 inches of vacuum) Proof dry, slightly cohesive, and divides in two parts, nearly round, but unequal, the bottom part being larger than the top part.

2nd Proof. (Steam at 3 atmospheres, 2/10 or 18¼ inches of vacuum) Proof a little denser which divides into two parts nearly equal, commencement of cohesiveness.

3rd Proof. (Steam at 3 atmospheres, 3/10 or 18½ inches of vacuum) by the separation of the fingers 2 or 3 centimetres, the proof forms a thick mass larger at the bottom than at the top, and resembling two cones joined at the top. The mass breaks easily and takes the form of a club.

4th Proof. (Steam 3 atmospheres, 4/10 or 18¾ inches of vacuum) Proof thicker, allowing a greater separation of the fingers without breaking. The mass thinner. When it breaks it shows a fine twist with a shadow at the upper part of the break.

5th and last Proof. (Steam 3 atmospheres, 5/10 or 19 inches of vacuum) Syrup dense and sticky, adheres fast to the fingers, the drop forms a united mass which breaks when the fingers are opened quickly, the top part rises, contracts and twists in the form of a corkscrew and the end twists inwards. When the mass breaks by the simple

opening of the fingers and thumb, without any particular movement of the latter, it is said that the *boiling is a light crochet* (according to the author, this is the best point at which to obtain maximum supplies and well crystallised products). The point of forming the grain is naturally regulated according to the quality of the syrup.

When the mass is required to be boiled very compact or thick, it is necessary to wait until the proof is broken by the deviation of the fingers, in which case the thumb must be used, when the proof will divide into two exceedingly thin parts, the top part being in the form of net work as at first. This proof is named heavy crochet.

II.—FORMATION OF THE GRAIN.

It is of the greatest importance to the yield to boil to a regular grain. To make ordinary crystals the following is required :—

1st. To boil with syrups of low density, say from *17°* to *18°* Beaumé.

2nd. The boiling point must be low until the first crystals are formed, so that not much grain is formed at once, and to give these time to enlarge.

3rd. To supply freely according to the capacity of the apparatus, so that the crystals are formed slowly and without difficulty.

4th. To boil slowly and regularly, to maintain the stability of the vacuum and steam, by allowing the hands of the gauges to oscillate, with a variation of $\frac{1}{10}$ atmosphere and about $\frac{1}{4}$ inch of vacuum.

5th. To increase the vacuum by *1* or *2* inches with syrups *of low density*, say from *16°* to *17°* Beaumé, diminishing it by a fraction equivalent to the density of rich syrups to accelerate the crystallisation of the first and to delay that of second.

To obtain the above results, the practical working must be as follows :—

1st Charge of the syrup to form the grain, open the steam supply valve *3* or *4* turns and wait *5* or *10* seconds, according to the consistance of the syrup, and then shut it, the boiling will be clear and pass over the sight glasses four or five times quicker, the steam and vacuum gauges will fall from *3½* to *3* atmospheres, and the vacuum from *19* to *18* inches, so that each deviation of *1°* of the steam gauge corresponds with a double displacement of the thermometer. In about *4* or *5* minutes the interior liquid returns to the boiling point.

2nd Charge. The same quantity as the first, which is an indispensable condition to obtain equal grain. As far as the quantity is concerned, it is difficult to determine, and is of little importance as it varies with the dimensions of the pans, and the density of the syrup. In general, the first charge represents *2/5* of the total capacity, and *3/5* for the remaining charges. This charge should be about *1/50* of the syrup which has to be supplied. *15* or *20* equal charges are first made, after which the supply must be continual the moment the grain is large enough.

3rd Charge. Equal to the two first till the syrup again boils.

4th Charge. Ditto, &c. The supply valve or cock being regularly opened, the charges should take place at intervals of *4* or *5* minutes. The mass must *not be boiled too hurriedly or it causes new grain* to be formed; it is very easy to see when this occurs, as after the supply the boiling coming against the sight-glasses fades immediately and turns straw yellow, forming a mass of bubbles, *which appear stealthily and boil as a drop of* water falling on a heated plate. The proof-stick and the steam gauge must be inspected.

With good syrups the grain is formed after the 5th or 6th charge. The regular charges are continued until the grain is well formed and hard, which generally takes place after *15* or *20* charges, when the density of the syrup *is* regular, the indications of the *steam* gauge *will also* be regular. If the syrup is bad, the forming of the crystals

take a much longer time, there must be no anxiety about this, but continue working regularly and they will form. After the *15*th or *20*th charge, when the crystals are sufficiently formed, the supply may be more copious, to prevent the formation of new crystals, and to develop those which have been formed. The charges must neither be too small nor too great. On the sight-glasses it can be seen if there are grains enough when they cover about 1/10 of the total surface, the appearance of the drops on the sight-glasses will be nearly opaque, and the mass will have taken a characteristic dull grey colour. Good syrups require about *one* hour to come to that point, and inferior syrups *two* to *three* hours.

III.—THE PROCESS OF PROMOTING THE GRAIN.

The super-saturation which causes new grains must be avoided, consequently the syrup must be dissolved in a sufficient but not exaggerated manner :—

1st. The syrup has a suitable density when the drop adheres in a certain measure to the sight-glasses, and descends at a rate not exceeding two to three millimetres per second, sliding down the sight-glass, the scum or bubbles which cover the drop fall off and leave uncovered a little or small stripe of granulated syrup, which flows twice as slowly, and of which the aspect, the compactness, and the granulation, show the progress of the boiling.

2nd. The syrup is too dense when the drop glides with difficulty on the sight-glass, and appears nearly attached, the scum has much difficulty then in separating from the syrup, which gives after each supply nearly an invisible light yellow colour.

3rd. The syrup has a very low density when the drop and scum adhere only slightly on the sight-glasses, and glides easily off, leaving only a slight visible trace.

PRACTICAL WORKING.

When giving the first charge the valve or cock to be open for *15* to *20* seconds, then must be observed what

takes place. There must be no anxiety about the grain, when the first charge is very copious, the mass must be allowed to form, then a second, third, and fourth charge are given, which must be exactly equal. During this time *the steam valves or cocks must be regulated so that the* steam gauge in the first part of the boiling only shows a deviation of 2 or 3 tenths, and the vacuum gauge ½ to 1 inch. When these elements are constant after 4 or 5 successive charges, a continual supply can be commenced. Therefore the steam valve or cock must be opened 2 or 3 turns at most, attentively watching the steam and vacuum gauges, and the boiling in order to proportion the volume of the liquid to that of the syrup supplied. When *the working is well regulated the sugar boiler has only to* pay attention to the progress of the evaporation.

When the syrup covers the second serpentine the steam is admitted, opening at the same time the syrup supply valve ¼ or ½ c.m more to make up the supply lost by the evaporation, and which must be regulated as *before; at the same time attention must be given to the* vacuum which is on the point of falling, and which is regulated by means of the injection water and air pump. When the third serpentine is covered by syrup, more steam is admitted following the indications above, then the steam pressure will fall, but it is maintained at 2½ atmospheres, and the vacuum at 19 inches. The quality of the boiling must also be observed, if it is thick, or dry, as the more it is hurried the better it is. The boiling is *good when the grain separates easily from the molasses,* adhering to the fingers when plunged in cold water, if the grains are sticky or gummy the boiling will be thick, when more syrup must be supplied to enlarge the crystals, which assures an easier purgation.

After 6 or 10 hours a more progressive concentration *must be looked for.* The mass *then reaches the height* of the third sight-glass. No matter what happens the boiling point must be steadily maintained, the supply valve or cock being closed a little to raise the vacuum from 19 to 21 inches. 1½ to 2 hours before finishing, the steam must be raised to 3½ atmospheres for a few moments c heat the mass, which will harden the crystals, then the syrup supply is stopped and the compression (serrage) of the boiling is commenced.

IV.—COMPRESSION (SERRAGE) OF THE BOILING.

At this point the supply valve or cock being shut the stop valve of the general steam pipe will be about ¾ closed and the pressure in the serpentines will be reduced from 6 to 8 tenths of an atmosphere, which pressure is sufficient to finish the boiling. The vacuum will then rise to 22, 23, or 24 inches. Every time the vacuum gauge indicates *one* degree more, a small supply of syrup can be given for 3 or 4 seconds only, to enlarge the crystals. Then the mass undergoes the commencement of purgation or diminishing which makes it less gummy and easier to compress, and three equal charges are supplied at intervals of 8 or 10 minutes, so that the boiling will not be delayed too much, this is only to wash the grain and not to enlarge it.

The limit of the final drying is difficult to be determined. A bad thick boiling must not be too much compressed, but as much as possible with a good boiling (in the centrifugal machines from *one* to *two* hours after the strike has fallen). The compression is very easy, when the grain rolled on the fingers separates easily on being put into water. After twenty minutes or half-an-hour the proof separates with difficulty from the end of the proof-stick, and taking it on the end of the thumb, it takes the form of a pastile. At this point, the evaporation is completed, and the steam must be completely shut off immediately. The vacuum will then rise and the mass will cool down, when *one* or *two* small charges of syrup are given, but less than the preceding ones, at intervals of 10 or 12 minutes, while a proof is taken with the proof-stick every 4 or 5 minutes, according to the experience of the sugar boiler. When the boiling comes against the sight-glasses it will be duller owing to the intensity of the grain. The compression (Serrage) can be brought to its last limits by use of the proof-stick, the proof being compressed between the finger and thumb, and when raising the finger gently the proof separates without the syrupy membrane; the hard grains enlarged by clear syrup when placed on white paper the paper absorbs the syrup leaving a clear crystal. If on the contrary the mass is gummy and sticks to the fingers in many parts, precautions are required, viz., that the compression

(Serrage) may be carried as far as possible, then a small supply of syrup must be added, when this is carried out it will easily be centrifugalled. With good syrups, the boiling can be considered finished when the proof taken falls easily on the thumb and forms a cluster-knot with difficulty. At this point the boiling or strike must be allowed to fall, at the same time shutting off the injection water and stopping the air pump. Destroying the vacuum until only 5 or 6 inches are indicated, admit steam for cleaning out the pan and to detach the particles of sugar adhering to it, also to clean the sight-glasses and empty the vessel.

REMARKS.

This interesting document is given in full, because it is probable that sugar boiling will long be continued in this manner, but there are still several points to be noted. The inventors of boiling in a vacuum, boiled with all the vacuum that could be formed by the apparatus, the mass is then cooler, but the balance of the pressure of steam and vacuum in the apparatus always remained, only with this difference, that the vacuum being constant, the pressure of the steam must vary to maintain a constant boiling, whilst in the process described by Mr. Leluy, the pressure of vapour and vacuum vary at all times. But a point of more importance is that of the syrup supply, when the mass is very hot, syrups of light density must be supplied, whilst in a cooler mass, there is no objection to supplying syrup of a high density, as the evaporation being nearly nil when approaching boiling point, it can be easier delayed, therefore in the different French factories provided with the new apparatus of Mr. Rillieux by which the boiling is done at a low pressure, syrups of 25° to 30° B. are supplied without any difficulty, producing the ordinary grain that is required by the sugar market. When dense syrups are supplied they offer a great economical advantage, the evaporation in the pan is thus a simple Effet, and if the syrup is evaporated to as high a density as possible in the Triple Effet, only a third of the steam will be used in the vacuum pan, which represents a very large sum in fuel at the end of the working season, all is thus in the favour of boiling with high vacuum and low pressure, except when large grain is required in

vacuum pans with a high belt or calender, when it is impossible to boil with steam of a pressure less than *one* atmosphere. Take for example that the average height of the mass is 6 metres above the centre serpentine, the density of which is 1·42, the steam formed on that serpentine has, when escaping, to overcome a pressure of *one* atmosphere, therefore the pressure in the serpentine must be higher to furnish the amount of steam necessary for the boiling, also a higher pressure will be required in the bottom serpentines. In this case only direct steam must be used, but in all other cases it will be a great advantage to boil with the maximum of vacuum and the minimum of pressure in the serpentines.

OBSERVATIONS ON THE DISTRIBUTION OF STEAM.

In the distribution of the steam in a factory there are several rules to be followed, whether it be steam of high or low pressure, whether it comes direct from the boilers to the engines, or to the serpentines, or from the receiver in which the exhaust steam from these same engines is accumulated, to be used in the Triple Effet, or in the centrifugal machines. Dry steam must be used as much as possible, that is to say, steam free of all condensed water, which is generally deposited at the bottom of the different pipes, and in the steam cylinders of the engines, &c. These different points are often required to be cleared of water, and it is best to connect the boilers by a horizontal steam receiver of sufficient diameter, to which the main steam pipe is connected. This receiver must be so arranged that the condensed water formed therein can easily fall back into the boiler. The best manner to dry steam or vapour, (as has been stated elsewhere in speaking of Triple Effet apparatus) is to circulate it in a space sufficiently large, so that its velocity is checked at once, and thus the heavy bodies in the steam naturally fall to the bottom. This is why the steam receivers are placed in that part of the factory where dry steam is required. These steam receivers have other useful properties, viz. :—With the steam or vapour there escapes a certain quantity of air which is dissolved in the water, this air is very prejudicial to the heating of the serpentines, as it offers by its presence an obstacle to the condensation, it

being a bad conductor of heat. In the engine steam cylinders it has not the same effect as the steam, which place it occupies, and takes the properties of exhaust steam. This air is also prejudicial to the heating of the Triple Effet as well as the serpentines, so that it must be drawn out of the steam or vapour as much as possible, as it is heavier, its presence in steam or vapour in a receiver can easily be detected by drawing the hand over it from top to bottom, the part containing the air will be rather cool. This air can be drawn off at the bottom of the receiver with the condensed water, by means of a small cock or valve, or a condensed water box or trap.

A direct steam receiver is a great advantage when many pipes have to be taken in different directions, as they can all be attached to the receiver, all acute angles must be avoided in steam pipes, all the necessary bends being made easy for the passage of the steam. If the velocity of the steam coming from the boilers is checked by the interposition of a receiver, and if at the same time all the different pipes were connected to the receiver, it might be possible to avoid a great loss from the multiplicity of the right angles. Pipes of large dimensions must be used if possible, in consequence of the large number of bends which are obliged to be used in the complicated arrangement of a sugar factory. We have seen in a factory, engines for driving the centrifugal machines much larger than are necessary under the circumstances, and had much difficulty in doing its work notwithstanding that the steam stop valve was full open, this was caused by it being too far off, and the steam connecting pipe being too small, this also causing a loss of the exhaust steam. It is evident from this that the original pressure of 5 atmospheres on the boilers was reduced to 3 atmospheres, and possibly to 2 at the end of this pipe. It is indispensable that all steam pipes and steam receivers should be covered with a non-conducting composition, to reduce the condensation to a minimum, by which there will be gained at least 20% more effective power from the steam or vapour, this will give some idea of the large amount of condensed water that is required to be got rid of from uncovered pipes. The ends of all pipes should be provided with drain cocks. The boilers should be as near as convenient to the factory, so that the steam pipes can be made as short as possible and with the fewest bends. The working of the boilers will not be treated of here,

being a separate part of the factory which it is the engineer's duty to see attended to, as well as to the working of the engines. The principal thing with the boilers is to see they are regularly fired, and the steam kept at a uniform pressure, so that when steam is taken away suddenly (which occurs sometimes when boiling with the vacuum pan) it is not much felt in the boilers. As regards the best type of boiler to use it is difficult to decide; but those which are most economical in fuel, and easy to inpect should be preferred.

The ordinary boiler with bouilleurs is very cumbersome, and is not economical in fuel, and according to the inventors it is difficult to produce with this class of boiler more than 6 or 7 kilos of steam per kilo of coal, while there is obtained with the most tubular and semi-tubular boilers 9, 10, and even 11 kilos of steam per kilo of coal. By using the last named type of boiler there is a great economy of fuel.

Boilers of the locomotive type, having no brickwork are very easy to handle and control. The ordinary tubular and semi-tubular boilers with bouilleurs are more economical and take up less space, but they are built in brickwork and require more precaution in working and inspecting, on account of the unequal expansion to which they are submitted. There are many other types of boilers uniting the advantages of these different boilers in variable proportions. In a country where there are good workmen the most perfect semi-tubular boiler may be used, but in the interior where the boilers are entrusted to inexperienced workmen the ordinary tubular boilers are preferred, and even when the coal or fuel is cheap the large bouilleur boilers are preferred.

Now will be taken into consideration the system of Rillieux, which consists of using the heat lost in the flues of bouilleur boilers to heat a tubular low pressure boiler, which acts as receiver for all the condensed water formed in the factory, and also as a steam receiver for heating the Triple Effet and different other uses. This system gives a great economy of fuel.

VAPOUR AND CONDENSED WATER.

The exhaust steam of all the engines in the factory passes through pipes which are connected to one large

main pipe, generally made of cast iron, and named the pipe for exhaust steam and condensed water. To this pipe are connected all the condensed water pipes for the different serpentines used in the different pans, and it flows into a closed condensed water receiver, and is tapped or drawn off from the bottom by a large syphon, which causes a counter pressure equal to that of the exhaust steam, this arrangement is not good, as the pressure is not always constant in the receiver, so that when it surpasses the limit fixed by the length of the syphon, it empties itself and the steam or vapour escapes. It is preferable to provide the receiver with a float-cock or valve by which the outflow of the condensed water is regulated, and the pressure must be so that it does not interfere with its working. The Multiple Effet is supplied with steam or vapour from this receiver by a large cast-iron pipe, and direct steam is admitted into the receiver to regulate the evaporation in the apparatus, the top part of the receiver is provided with a safety-valve, which is opened to the air to allow the escape of the steam when the apparatus is not working. The condensed water from the receiver flows into a tank, into which all the condensed water from the factory is accumulated and which is drawn off by a pump to feed the boilers; this condensed water is of a high temperature, which is reduced when exposed to the open air, and all the vapour arising from it is lost, which should not be allowed, so that a closed receiver is preferable in order to maintain a certain pressure, which is far from prejudicial to the supply, as it will facilitate the working of the pumps. This receiver must be fitted with a valve or cock, through which the incondensable gases can escape with a little steam or vapour into the air.

WATER REQUIRED FOR A FACTORY.

The water is supplied by a special pump placed in the factory to avoid the frost, and which delivers the water into reservoirs placed in the top of the building. It is immaterial what system of pump is employed so long as .. gives the required quantity of water. Pumps with valves which are easy to regulate are often used, but rotary pumps do not take up so much space. The suction pipe must be kept particularly clear, as it is indispensable that the water

should be absolutely clean and free of all organic impurities, and to attain this the suction pipe should have a valve with a grating or perforated plate which should be some distance from the bottom of the well, so that it cannot take up sand or dirt. When the suction pipe is placed in a lake or river it is necessary to close it in with a wooden casing, to keep any floating matter from being drawn in. This casing can be formed in two parts, an outer and an inner, and filled with stones between the two to filter the water.

In factories where the water is not abundant, that coming from the Triple Effet and vacuum pan air pumps, is collected in artificial reservoirs, where it is cooled and again used for the condensation. When there is no place in the vicinity of the factory to make these reservoirs, a cooling apparatus may be used. Mr. Rillieux uses a sort of square box in which are hung canvas screens very close together, on which the water to be cooled falls; a current of air is directed by a fan through the bottom of the box which causes the evaporation of a certain quantity of the water, and produces a considerable reduction of temperature, the water so treated flows from this at some degrees lower than the surrounding temperature, the temperature of the water being regulated by the speed of the fan. This is the most perfect apparatus for cooling water.

In France this is substituted by an apparatus which is not worth the tenth part of Mr. Rillieux's apparatus, this is formed of a wooden pile work having many courses on which fagots are heaped up, the water is brought from the lower part to the top by means of a pump, and then falls on the fagots where it is cooled rapidly. But what is cooled is not so pure as natural water so far as regards organic matters, and as a large quantity is lost which must be replaced, it is much better to use fresh water for the other purposes and this water only for the condensation.

This water has a certain value in countries where the water contains lime and chalk. After the condensation the salts are deposited in the vessels where the increase of temperature was effected. This water is thus very pure in comparison with the natural water found in the country, and must be preserved with precaution and cooled off, and used in preference to any other, and it will repay the

manufacturer by the absence of incrustations which are caused by using impure waters. It has been proposed to filter the water through animal charcoal or coal to take off the organic impurities, this may be done for the water necessary for the boilers or for any other use without filtering all the water, and a small quantity of unfiltered water can be added for other purposes in the factory. The same results will be obtained in countries where salt water is obtained in abundance. There may be no anxiety about accidents by the use of water containing lime.

CALCULATIONS

FOR THE

DIMENSIONS OF A FACTORY

TO WORK OFF

THIRTY FIVE MILLION KILOS OF BEET-ROOT IN 100 DAYS.

BEET-ROOT MAGAZINE.

Supposing that the factory receives all the beet-root in its store, without the rasping machines, it must be capable of holding beet-root for 12 hours working. It would require an area of 225 square metres, or 15 metres × 15 metres, the beet-root being stored 2 metres high, which is the possible maximum. These measurements will give a capacity of 450 cubic metres or 249,000 kilos, being enough for night work. To have a larger quantity of beet-root there must be in the vicinity more stores, which should be provided with rails and waggons for easy transport.

ELEVATORS.

There are three of these placed in the beet-root store at equal distances from each other, so that they take up an equal quantity of beet, the first being 3 metres from the end of the store, the second at 4·50 metres from the first, and the third 4·50 metres from the second, which will place the last 3 metres from the other end of the store. The top of the elevators are placed 4 metres above the ground line, and are high enough to deliver the beet into the funnels of the washing machines. Opposite the centres of the elevators a clearance must be made between the heaps of beet-root, through which the waggons pass for unloading; when possible it is best to have a raised road for the waggons, say from 1·50 to 2 metres above the ground line which will make the unloading very much easier.

WASHING MACHINES.

Each elevator must have a washing machine 3 metres long × 1 metre, fitted with an arrangement for separating the dirt and gravel from the beet, and requires 5 H.P.* These machines are placed in the beet-root store, the centre of which is 2·50 metres from the ground line, this height is given on account of the dampness caused by the water; the beet-root is delivered from these machines into an inclined gutter placed against the wall of the factory. Total horse power required being 15. When diffusion is used in place of the washing-machines with the arrangement for separating the dirt and gravel, more power would be required for the rasps.

RASPS.

When wooden rasps are used, there are three for each 120,000 kilos of beet-root, each requiring about 8 H.P., giving a total of 24 H.P., each washing machine delivers the beet into the corresponding rasp.

The rasps of Champonnois will work off 63,000 kilos of beets in 24 hours, placed in six groups of 2 and 2, each group being served by *one* washing machine which has a sluice divided into two parts, each rasp requires a little more than 3 H.P.; an engine of 20 H.P. will be sufficient to drive them.

When these rasps are used it is unnecessary to place the washing machine above the ground, and there is a great advantage obtained by having this machine fitted with the arrangement for separating the dirt and gravel, and an archimedian screw.

PRESSES.

The continual presses for diffusion should be substituted by hydraulic presses. These latter will not be treated of here. In place of these, the continual presses of Mr. Champonnois will be described, which are capable of working 50,000 kilos of beet-root, and of which 7 will be required, being placed on the same platform as the carbonatation tanks, and above the rasps, at the side of the rasps are placed the pumps for supplying the presses, these are termed the first presses, to which are added *three* more for

* French H.P.

the second pressing, and placed in the same line as the seven, requiring a space or length of 20 metres. The same counter-shafting can work the rasps and the washing machines; about 20 H.P. will be required to work the presses and appurtenances. Thus a total of 60 H.P. is required to work the presses, rasps, washing machines, and elevators.

By using Manuel and Socin presses the second pressing is not required, 7 of these can treat 50,000 kilos of beet, and an ordinary pump or chain pump for working each press or a group of presses can deliver the pulp for the supply of the rasps, 10 H.P. will be sufficient to work these presses, which is a saving of 10 H.P. over the preceding installation, the same number of workmen being required in both cases; the area required for the Manuel presses is much greater, but the length taken up will be less. The juice from the presses runs into the first carbonatation tanks placed below, and the pulp is discharged into small waggons by an endless belt fitted with scoops, which is placed alongside of the presses. When diffusion is used two batteries are required.

CARBONATATION.

The carbonatation with gases of ordinary quality requires two hours, charging and emptying half-an-hour, when one carbonatation and *one* settling tank are used, the time required for the juice to settle is half-an-hour longer, making three hours for each carbonatation and settling, so that *one* tank can work eight times in the 24 hours. To work off say 3,500 hectolitres a carbonatation tank capacity of 440 hectolitres is sufficient, requiring *ten* tanks, each 1 metre broad × 3 metres deep × 2·50 metres long, having a capacity of 4,655 litres. The second carbonatation requires about 20 minutes, or an hour and a half for the whole process, so that four tanks will be required, making a total of fourteen.

MONTJUS OR PUMP.

In order to bring the juice from the first to the second carbonatation tanks, how much steam will be used when employing a montjus to work off 3,500 hectolitres? At

first there will be required 3,500 hectolitres of steam at 5 atmospheres, weighing about 2½ kilos per cubic metre, or 875 kilos of steam, every time the montjus, which has a capacity of 50 hectolitres is filled and emptied (which is the capacity of one carbonatation tank) will weigh about 800 kilos. When the juice in the montjus is at a temperature of 90°, and the steam used being 152°, the difference will be 152°—90°=62°, the specific heat of the sheet iron of the montjus being 0·114. There is required to heat the montjus from 62°

$$800 \times 0{\cdot}114 \times 62 = 5654{\cdot}4 \text{ calories,}$$

representing $\frac{3{,}414}{689-90} = 5{\cdot}69$ kilos of steam, which will give a total of 455·2 kilos of steam in 24 hours, the montjus having to be emptied 80 times. This total of steam is a little too high, as the temperature 152° is not continued to the end of the emptying, as it would be difficult for regular working to use *one* montjus 80 times per 24 hours, two are used, so that the sheet-iron bodies of both will have to be heated, and owing to this a greater quantity of steam will be used. The heat of the juice being 90° coming in contact with steam at 152° must be taken into consideration, supposing that only a height of ten centimetres is heated with the ordinary temperature of $90 + \frac{152-90}{2} = 121$ giving a difference of 31° in the temperature of the steam. Suppose the montjus to have an area of 1·32 square metres, and the juice a density of 1·04, there will be a weight of juice $1{\cdot}33^{m\cdot} \times 0{\cdot}10 \times 1{\cdot}04 = 138$ kilos, which will require $138 \times 31 = 4{,}278$ calories, or $\frac{4{,}278}{689-121} = 7{\cdot}50$ kilos of steam $\times\ 80 = 600$ kilos of steam, and it must not be overlooked that the steam contained or used in the montjus is exhausted into the atmosphere and lost, whilst the steam from a pump is used to heat the Triple Effet, and also that the steam condensed in the montjus must be evaporated in the Triple Effet. Without taking this into consideration, it will be seen that a montjus requires as follows :—

Steam for forcing out the juice	.. 875	kilos.
„ condensed in the montjus	.. 445	„
„ „ „ juice	.. 600	„
Total,	1920	kilos.

Taking 25 kilos of steam as representing 1 H.P. this will give a total of 77 H.P. in 24 hours, or to take off the

juice only 35 H.P. or 3·2 H.P. per hour or 1·5 H.P. to empty the montjus. This shows the enormous quantity of steam that is necessary to work such a mass of liquid with a montjus.

Supposing the juice is raised 10 metres by means of a pump, and taking the quantity to be delivered at 350,000 litres or 364,000 kilos, in 24 hours or at the rate of 4·21 kilos per second, equal to 42·10 kilogrammetres or $\frac{42 \cdot 10}{75} = 0 \cdot 56$, so that the power required will be about ½ H.P., from which will be seen the enormous difference in favour of the pump over a montjus.

HEATING SURFACE OF THE SERPENTINES IN THE CARBONATATION TANKS.

The heating necessary for boiling 350,000 litres of carbonated juice is equal to 110 H.P. of steam per hour. This heat is given off by serpentines which are placed around the inside of the tanks, and at a sufficient distance from the sides to allow of easy cleaning. The heating of these is calculated as follows:—Each tank having a capacity of 4,655 litres or about 4,800 kilos of juice, this under ordinary conditions being 0°, and to bring it up to 100° there is required 480,000 calories, taking the specific heat at 1, a number from which it differs very little. The pressure required to boil the above will be about *four* atmospheres, and the back pressure will be about *one* atmosphere, that is to say, when the steam is condensed at 121° the average will be $\frac{0° + 121°}{2} = 60 \cdot 50$. The steam condensing gives $537 + (144 - 60 \cdot 5) = 620 \cdot 50$ calories; to again heat the juice there is required $\frac{480,000}{620 \cdot 5} = 797 \cdot 74$ kilos of steam. One square metre of the serpentines will condense 2·5 kilos of steam per hour, and per degree of temperature of the liquid. The reduction of the heat or temperature is here $144 - 60 \cdot 5 = 83° \cdot 5$, therefore one metre of surface under these conditions can condense 208·75 kilos of steam, and to condense 797·74 kilos of steam, there is required $3 \cdot 82^{m}$ square metres surface in the serpentines, the condensation being calculated per hour, at the same time the condensation is very quick, say in about 10 minutes. If steam at *one* atmosphere is used, the heating surface must be six times larger, say from 22·92 to 23 metres, the steam

having at this pressure a temperature of 121° equal to 608 calories, will require about 800 kilos of steam to do the work, *one* square metre of serpentine will then condense 175·5 kilos of steam, and to condense 800 kilos per hour 4·50 square metres is required, or per 10 minutes, 27 metres.

The required diameter of the coils is determined by the number to give the above surface, thus if the tanks having 2·50 metres, with 20 coils at a height of 2 metres the distance apart will be about 7 centimetres.

LIME STONE.

The first carbonatation is supplied with 20/1000 and the second 6/1000 which makes a total of 26/1000 to work 350,000 kilos of beet root 9,100 kilos of limestone will be required in 24 hours, add to this 10% for loss, &c., it will give 10,000 kilos of lime.

17,900 kilos of limestone	or about	14 c/metres.
1,620 „ „ coke	„ „	4 „
	Total	18 cubic metres.

The lime kiln must have a maximum of useful capacity, say 3 × 18 or 54 cubic metres, it will be more advantageous to use a large quantity of lime for the work. At "Meaux" in 1874 and 1875, they worked off the same quantity of beet-root, viz., 350,000 kilos, and used 23,000 kilos of Epernay limestone, or 17 cubic metres, giving 16,800 kilos of lime, which corresponds to a lime kiln capacity of 76 cubic metres. The limestone required for 100 days' working will be from 1,400 to 1,700 cubic metres, which is stored in an open shed.

LIME MILK.

When the lime milk is composed of 20% of lime, say 80 kilos of water and 20 of lime, there will be required about 40,000 litres of water. To avoid the unnecessary evaporation of such a large quantity of thick liquid, it is easier to use the juice from the first carbonatation and filter presses, at the same time water is used in all cases, when the lime milk tank is not higher than the carbonatation tanks, a montjus must be used for forcing it up, which will require 4 H.P. of steam.

GAS PUMP.

The gas, which contains 23% of carbonic acid, is drawn off from the top of the lime kiln by a pump, it has, therefore, to extract about 17,900 cubic metres of gas per 24 hours, at one revolution per second, the diameter of the piston being equal to the stroke, the pump being 80 c/m diameter for supplying the carbonatation tanks with gas, the power required to work the pump is that produced by the weight of juice on a given surface, the carbonatation tanks being 3 metres high, the pressure on the piston will be about 1,500 kilos, equal to 32 or 33 H.P. The pipes for supplying the gas are 30 centimetres diameter, which gives an allowance for a long pipe with bends.

GAS WASHER.

This has a diameter of 1·400 metres × 2 metres high from under the top part, the gas pipe is placed in the centre, in case the gas is not pure, a second washer must be used.

FILTER PRESSES.

The sediment of the carbonatation is taken as a maximum of 12% of the beet-root, which will be 42,000 kilos for 350,000 kilos of beet-root, to do this work 12 of "Trinks" presses with 18 chambers are sufficient. It is difficult to use any other apparatus than a montjus for forcing through the liquid, *two* are used, each having a capacity of 2,500 litres, having a tank between them of the same capacity. The quantity of sediment that comes from the carbonatation tanks to the filter presses is about 100,000 litres, and the volume of steam necessary to work the montjus and to clean the presses is equal to 11 H.P. Compressed air is used in preference to steam.

THE TRIPLE EFFET SUPPLY TANK.

On leaving the filters the juice runs into a tank close to the Triple Effet, the capacity of this varies, being generally from 3,000 to 4,000 litres, or 1·50 cubic metres. The Triple Effet is supplied from this tank by means of a pump, capable of delivering 500,000 litres in 24 hours ; the suction pipe is provided at the bottom with an automatic working valve, which prevents air from entering.

EVAPORATION.

The constructors give the following dimensions for a Triple Effet to evaporate 500,000 litres in 24 hours :—

	Diameters. Metres.	Surface sq. m.	No. of Tubes.	Dia. of Save-alls.
1st Vessel.	2·050	140·54	762	1·100
2nd "	2·330	203·28	990	1·100
3rd "	2·630	239·58	1213	1·100
Total		583·40	2965	

From centre to centre of 1st and 2nd vessel 2·755 metres.
" " " 2nd and 3rd " 2·930 "

It is preferable to use a Triple Effet having all *three* vessels of one size, which, with the above heating surface, could evaporate much more than 500,000 litres, and permits of all the washings of the factory, scum and diffusion, &c. being treated, and calculated to produce 100 per 100 of juice, the diffusion giving easily 120 to 130 and more.

In order to obtain a good vacuum a large pump must be used, these are often made much too small. In this treatise are given the theoretical calculations for the dimensions of air pumps. The pump for the above Triple Effet will have the following dimensions :—

Diameter of steam cylinder	..	0·450
" " pump	..	0·750
Stroke ..	..	0·800

Revolutions per minute 40 to 50.

100,000 litres of injection water is required per hour for the condenser, the air pump requiring a maximum working power to overcome the atmospheric resistance of the piston, which is about 70 H.P.

RE-HEATING THE SYRUP.

When the syrup leaves the Triple Effet it has a temperature of 50° and is drawn off by a pump and delivered

into tanks where it is re-heated; when a montjus is used in place of a pump it requires 10 H.P. of steam. There will be about 64,000 litres of syrup at a density of 20° Beaumé when cold, which will boil at a temperature of 103°, so that it will be required to be heated from 50° to 103°, giving 53° to the liquid, the specific heat of which is 0·6 and the density 1·26, so that 4,775 kilos of steam will be required in 24 hours, equal to 8 H.P.

BOILING TO GRAIN.

The syrup after the filtration has a temperature of about 40° in open fire, grain forming when the temperature is about 115°, and the syrup boiling at 103°, giving a difference of 12° in the boiling point of the two liquids. The average difference of temperature in the middle of the operation will be from 6° to 9° above that of the vapour which comes from the liquid. The vapour being 60° the liquid or syrup will boil at 69°, so that the syrup is brought from 40° to 69° by adding 29° of temperature, the specific heat of the boiling mass being about 0·5, when the steam is supplied to boil or evaporate it from 30° Beaumé to masse cuité, leaving only from 8 to 10 % of water in the mass, or in other words 39% of water has to be evaporated out of the syrup. So that from 64,000 litres or 80,640 kilos of syrup 31,450 kilos of water will be evaporated.

To raise the heat of the syrup in the vacuum pan 29° there is required $80{,}640 \times 29 \times 0{\cdot}5 = 1{,}169{,}280$ calories, and to evaporate 31,450 kilos of water 16,888,650 calories, this heat being supplied by direct steam at 4 atmospheres, having a temperature of 144° and the condensed water in the vacuum pan serpentines 69°, so that the steam while passing from 144° to 69° gives off $537 + (144° - 69°) = 612$ calories. So that to raise the heat of the syrup $\frac{1{,}169{,}280}{612} = 1910{\cdot}6$ kilos of steam are required and to boil it to masse cuité 27,595·8 kilos, which represents 1,180 H.P. of steam. To form masse cuité requires about 10 hours, so that 118 H.P. of steam is required per hour. It must be taken into consideration that the evaporation is much quicker at the commencement than at the end, so that more steam will be used at the first than at the last, this large quantity of steam

being only required during a certain time of the boiling, makes it sometimes difficult for the boilers to keep up the supply. It is the place of the Sugar Boiler to see that the firemen have steam enough at the commencement, otherwise the whole process will be stopped; and also to have it in their power to reduce it when required.

Each strike requires for condensation 500,000 litres of injection water.

In general 10 % of masse cuite is produced from the weight of the beet, so that 350,000 litres of juice would give 35,000 litres of masse cuite, each strike takes about 10 hours, so that two could be made in 24 hours. For this, the vacuum pan must have an effective capacity of 17,500 litres, and of the following dimensions:—3m. 500 diameter, belt or calender 2m. 300 high, fitted with four serpentines having a total heating surface of from 55 to 60 square metres.

The air pump will be 500 m/m diameter × 550 m/m stroke and the steam cylinder 340 m/m, making 55 revolutions per minute, equal to about 26 H.P. When using one condenser and one air pump for the vacuum pan and Triple Effet, the engine would have to be 100 H.P., and would also work the pumps for drawing off the ammoniacal water, syrup, and the juice supply, which would cost less than each having a separate pump, and take up less space in the factory.

SUPPLY TANKS.

These must have a capacity of 35,000 litres, but as all cannot be centrifugaled in one day, from one cause or another, the capacity must be 70,000 litres in two or more tanks.

SUGAR PUG MILLS.

These are constructed to work 40,000 litres of masse cuite per day, and require about 2 H.P.

CENTRIFUGAL MACHINES.

Each of these will work 50 kilos of masse cuite, or 35 litres, to work off 35,000 litres of masse cuite would require 1,000 processes in 22 hours or 45½ per hour, calculating half an hour for each operation, 23 machines would be required, allowing 1½ H.P. for each, would give a total of 34 H.P.

WATER REQUIRED FOR THE FACTORY.

The water required may be divided as follows :—

Washers	14,000	litres	in 24	hours.
Rasp Water	35,000	,,	,,	,,
Double Pressure	105,000	,,	,,	,,
Lime Milk	40,000	,,	,,	,,
Filtration	160,000	,,	,,	,,
Triple Effet	2,400,000	,,	,,	,,
Vacuum Pan	1,000,000	,,	,,	,,
Animal Charcoal	300,000	,,	,,	,,

Total, 4,084,000 litres per 24 hours.

To this must be added the necessary water for the boilers to produce 600 H.P., which is equal to 360,000 litres in 24 hours, making a total of 4,440,000 litres, or in round numbers 4,500,000 litres, which have to be delivered to a height of 10 metres in 24 hours giving 187,500 litres per hour, with a double acting pump making one stroke per second, and a capacity of 26 litres, when drawing the water its full stroke, the pump will have a diameter of 218 m/m × 70, c/m stroke will require 7 H.P.

TOTAL QUANTITY OF STEAM REQUIRED.

The total horse power required for the fabrication is approximately 600, requiring 6 boilers each of 100 H.P., a seventh is supplied in case of repairing and cleaning. For supplying the boilers with water a feed pump is required. The boiler shed for the seven boilers will require to be about 17 to 18 metres wide when placed in one range × 12 to 14 metres deep. The centres of the boilers being 2 metres. The tubular boilers of 100 H.P. are made 1m.30 diameter × 6m.50 long.

FUEL.

Supposing that 1 kilo of coal will evaporate 9·8 kilos of water, the boilers will require about 360,000 litres of

feed water per 24 hours, and 36,700 kilos of coal, taking the sugar produced as 10 % of the beet root, it will give 35,000 kilos of sugar in 24 hours, so that to produce one kilo of sugar, 1 kilo of coal is required, (1·05 kilos being the result in central factories,) or 3,670 tons for the working season, which will occupy a space of 4,590 cubic metres, or 9,175 tons of wood, 15,300 cubic metres.

SECOND SUGARS.

360,000 litres of juice will give 27,000 litres of syrup, from which 6,200 litres of water is evaporated, leaving a mass of 20,800 litres. The vacuum pan used for the second sugars can be made two or three times smaller than that for the head sugars, as the boiling does not take so long, requiring only 11 H.P. of steam per hour. The tank capacity for the second sugars must be equal to 2,080,000 litres for 100 working days, when these are centrifugaled during the process, there is seldom a want of tank capacity, sometimes these are worked off after the fabrication is finished.

THIRD SUGARS.

The second sugars, after passing through the centrifugals, give 14,400 litres of molasses from which 1,200 litres of water is evaporated, leaving 13,200 litres, which are allowed to stand one year to crystallize, requiring about the same tank capacity, as this is also centrifugaled after the fabrication is finished, and gives for a second time 1,320,000 litres, which must be stored until the first sugars are worked off.

There is required for the refuse a capacity of about 2,800,000 litres, which would have to be increased if the beet-root gave more than third sugars.

MOLASSES.

The last molasses form about 3 % of the total juice worked or 1,080,000 litres. The storage of this is determined by the arrangement of the factory.

THE STUDY OF THE MULTIPLE EFFET APPARATUS FOR EVAPORATION.

Less than thirty years ago the manufacture of beet-root sugar in France was not the tenth part of what it is at present. The process of purification and concentration of the juice which is obtained by pressure of the rasped roots, which method was used in the Colonies for extracting the sugar from the cane, was neither economical nor favourable to the perfection of the products of beet-root. To work 1000 kilos of beet-root, 350 kilos of coal was required, the evaporation being performed by a fire under open pans, although steam had already commenced to be used.

From 1828 to 1829 Moulfarine and Pecqueur, the two principal constructors of the Multiple Effet at Paris, made apparatus for evaporation in the open air, composed of *pans fitted with pipes, in which the steam circulated*, and which were superior to those fitted with a double bottom.

About this time Mr. Howard invented an apparatus or pan, which had a double bottom, and the top provided with a dome from which there was a pipe for taking off the vapour that might accumulate into an empty chamber, which under the influence of injection water, was condensed and drawn off by an air pump, by this a vacuum was obtained equal to a column of mercury 50 c/m. This apparatus soon found favour in the Colonies, but the French manufacturers found it too intricate and with difficulty accepted it.

At this time, 1830, Mr. Rillieux who then lived in Paris, made his apparatus called a Multiple Effet evaporating in a vacuum, and at the same time it was thought that steam had a bad influence on the sugar, and that only open pans fired underneath were capable of burning it, and that it was better to make use of steam to avoid this. It is now known that steam of high pressure will easily form caramel of the sugar, and for this expensive experience thanks are due to Messrs. Moulfarine and Pecqueur. The caramel formed in the sugar by the use of steam had not escaped the quick perception of Mr. Rillieux, who thought at that time to make the evaporation entirely in a vacuum, by lowering the boiling point of the liquid, to avoid the pernicious influences of a

high steam pressure or temperature, so that it is not to be wondered, that the ideas and propositions of Mr. Rillieux did not at that time find favour with Moulfarine and Pecqueur to whom he proposed his apparatus, as they praised the use of direct or high pressure steam ; Mr. Rillieux could not convince them that they were wrong, and he finding a good occasion or chance to return to America, where a very satisfactory proposition was made to him, especially the hope or chance of applying his new apparatus, he departed and with him his invention, which only returned to Europe twenty years afterwards, but under deplorable conditions. One of the objections which was made to his apparatus was, it was too complicated, when already those of Mr. Howard had caused so much difficulty to learn. During the twenty-two years interval between the departure of Mr. Rillieux and the appearance of his apparatus in France, the French engineers had made no progress in respect to the question of economic evaporation of the juice, as they always adhered to the system on which Mr. Howard's steam evaporater was constructed. The vacuum pump appeared to the manufacturers and refiners at that time a machine which it was impossible to adopt in practice. At this time Roth tried to condense the vapour by means of a large quantity of water falling from a reservoir, which from time to time formed a vacuum, but the apparatus consumed more steam than that of Howard, yet afterwards he obtained good results. The refiners and manufacturers of sugar who were opposed to the introduction of the steam engine into their establishments, adopted his invention, and were the first.

Soon after this, Degrand fitted into Roth's condenser a long pipe, in the form of a serpentine or coil, and later Derosne in constructing the apparatus of Degrand, arranged the serpentine or coil in the form of a flat grating, the condensation of the steam or vapour in the serpentines was produced by the cold juice falling on them, so that here the juice commenced its concentration, which diminished the condensation considerably. The apparatus of Degrand had produced a great economy of fuel, which was based at from 200 to 250 grams per 1,000 kil s of beet-root.

Unfortunately this slow concentration in the open air, with heated pipes, produced such an alteration in the juices, that it was obliged to be given up, and the con-

densers with the usual column were then definitely adopted, with a large air pump to form a vacuum in the closed vessels or pans. The public opinion was ripe to adopt the Multiple Effet apparatus of Mr. Rillieux, as the air pump, the injection water, and the high vacuum, had already been put into practice. In 1852 when the above apparatus was about to be adopted, a German named Bramé Andrœa sent plans from America, based on Mr. Rillieux's apparatus, to the German Constructor Tischbein, from whom Cail bought them, and constructed Multiple Effets to these plans, which would not work as they were not made according to the original ideas, being made without any calculations or a clear idea of the apparatus.

After trials of more than 15 years, Triple Effets such as at present used in the French Sugar Factories were made. They are still imperfect, as they have not yet succeeded in reforming the beet root sugar industry by reducing the consumption of coals to 100 kilos per 1,000 kilos of beet root. During this time many manufactories were supplied with new machinery which produced better sugars, and being favoured by legislation the production became large, but ended when the exorbitant taxes were imposed with the protection laws of other countries, which produced the great crisis still felt at the present, 1882.

The principles on which the Multiple Effet apparatus are based will now be taken into consideration.

There did not exist a calculation for the Multiple Effet apparatus, so by the invitation of Mr. Cail in 1869, who knew with his own common sense, "as he said," that it was necessary to throw light upon the construction of the Triple Effet apparatus by theoretical studies which had never been made since its invention, experiments had been made, but without success, and the only result of any value being that Mr. Rillieux exposed the defective points to the constructors of this apparatus.

CALCULATION OF THE HEATING SURFACE OF THE MULTIPLE EFFET APPARATUS.

The Multiple Effet apparatus are those which are composed of a series of vessels each having a steam chamber, so that the heat or steam or vapour produced in the first, by the action of steam, heats the second, the vapour

or steam produced in the second heating the third, and so on until the last. There have been many patents taken out for this description of apparatus, among these the different apparatus of Pecqueur from 1829 to 1834, in which the last vessel boiled or evaporated in the open air, and the first with high pressure steam, thus by one source of heat, was produced theoretically the evaporation of as many times the quantity of liquid evaporated in the first vessel, as there are successive vessels. This apparatus may be used economically at any time, to evaporate liquids which may have to be brought or raised to a high temperature without fearing any change, but must not be used in factories where the juices turn to caramel at relatively low temperatures.

The vacuum pan of Mr. Howard was used with success in the Colonies and afterwards in France, as it had less pernicious influence on the sugar than the pans of Moulfarine and Pecqueur, which are fitted with serpentines and worked with direct steam.

At that time Mr. Rillieux got the idea of applying low pressure in the Multiple Effet, as he had described in his patent of 1845, which he published in 1848 in his Patent Office Report.

Now will be studied the principles of these apparatus, particularly the Triple Effet, which is most used in France.

These apparatus are composed of a series of vessels having tubular steam chambers constructed vertical or horizontal, in which a vacuum is formed graduated so that the liquid is boiled at a constant and low temperature which becomes lower according to the concentration of the juice.

The exhaust steam from the engines used in the factory provides the heat for the first tubular steam chamber, and in which it is condensed; when this exhaust steam is found to be insufficient for the work, direct steam must be added, the steam or vapour that is condensed in the first tubular steam chamber is generally used for feeding the steam boilers, as this steam chamber acts as a surface condenser does to a steam engine.

This exhaust steam has a variable pressure according to the necessities of the evaporation, the maximum of which should determine the proper speed of the engines,

and the juice in the vessels will boil better under the influence of this temperature as the pressure of the vapour it generates is lowered by the effect of the vacuum made above it. The vapour produced by the evaporation of the juice is condensed in the tubular steam chamber of the following vessel, where the juice is boiled to a high density, and also submitted to a vacuum. The heat necessary for the boiling is supplied entirely by the vapour from the first vessel. The effect produced by the vapour from the first vessel in the second is the same in the third, from the second, &c., and is the same in apparatus constructed as Double, Triple, and Quadruple Effets; the vapour from the last vessel is condensed in a special chamber by means of injection water. The vacuum is maintained in the last vessel by a pump, which also serves to draw off the injection water, condensed vapour, and the air in the water and apparatus. Sometimes there is used in place of the pump a vertical pipe 11 to 12 metres high, at the top of which is the barometrical vacuum, the water passing out at the bottom end of the pipe which is immersed in a tank.

Under the influence of the high vacuum the liquid begins to boil in the vessel, giving to the following steam chamber the heat necessary for the evaporation, the cooling produced by the evaporation causes the condensation of the vapour, which vapour circulates among the tubes filled with juice in the vertical apparatus, this condensation produces a partial vacuum above the liquid of lower density which begins to boil, and in the same manner produces a vacuum in the other tubular steam chamber, so that all that is necessary is to form a vacuum in the last vessel, and from there it is formed in the other vessels of itself, and by heating the first tubular steam chamber all the others are heated by the vapour from the evaporation in the different vessels, therefore the apparatus is named a Double, Triple, or Quadruple Effet.

The economical result which is obtained is in reality the following :—

By using the exhaust steam from all the engines in the factory, and only direct steam when the former is not sufficient for its work, will condense and evaporate an

quantity of water nearly equal to its own weight, multiplied by the number of steam chambers in the apparatus.

Now will be calculated the heating surface required by each tubular steam chamber, and to determine the exact condensation of the vapours in the conditions of time, heat and weight of liquid in each vessel. These conditions must be as economical as possible for which a general formulæ must be looked for to suit all possible cases.

Suppose P = The weight of juice in the vessel.
„ p = „ quantity of water to evaporate P.
„ T = „ temperature of the vapour.
„ t = „ initial temperature of the juice.
„ θ = „ temperature of the boiling.
„ q = „ quantity of vapour condensed to bring P to the temperature θ.
„ q' = „ quantity of steam condensed to evaporate P.
„ Q = „ total quantity of steam or vapour that is necessary to evaporate p, and to maintain the boiling during the units of time on the units of surface under the conditions of which the engine works.

C. The average specific heat of the juice in each vessel.

Thus, there are three conditions, the juice being supplied into the vessels, at the same or any temperature.

1st. Lower than the boiling point of the juice supposed to be $\theta > t$.

2nd. Higher than the boiling point of the juice supposed to be $\theta < t$.

3rd. Equal to the boiling point of the juice supposed to be $\theta = t$.

In the first case there is the sum of q and q' as the juice has to be heated. In the second case the juice gives off instead of absorbing the heat, which causes it to have a higher density and forward the evaporation, the quantity of heat produced by the lower temperature must be subtracted from that which is supplied by the exhaust steam to produce the boiling or evaporation of p. In the third case q = nil, consequently, if in the first or second cases you make $t = \theta$ you arrive at the third case.

FIRST CASE.—$\theta > t$.

The first effect of the steam or vapour is to raise P of the juice, from the temperature t to θ.

Passing from t to θ the juice takes $P\ (\theta - t)\ C$ calories. The *latent* and total heat of the vapour, which is condensed in the tubular steam chamber in order to heat the juice, are given by Regnault and Masson in the formula, viz.—

$$L = A + B.\ T.\ \text{in which}$$

L = The total heat of the steam or vapour.

T = The temperature of the steam or vapour which is condensed.

$A = 606{\cdot}5$

$B = 0{\cdot}305$

So that $P\ (\theta - t)\ C$ calories are produced by the condensation of q. In condensing q gives off

$$q\ (A + B\ T - \theta)\ \text{calories}$$

Again giving two quantities, viz. :—

$$P\ (\theta - t)\ C = q\ (A + B\ T - \theta)$$

$$\text{And } q = \frac{P\ C\ (\theta - t)}{A + B\ T - \theta}$$

Supposing that q condensing has the same temperature *as the juice which it has to heat*, that is to say a temperature of $\theta°$ which is visibly the temperature of the *condensed water.* When the juice is at a temperature of $\theta°$, the steam or vapour for heating has to evaporate p *kilos of water contained in the juice,* supposing q' equals the quantity of steam or vapour that is necessary, then q' *by condensing brings* $(A + B\ T - \theta)\ q'$ *calories.* P evaporating to $\theta°$ gives $(A + B\ \theta)\ p$ calories, there remaining a weight of juice equal to $(P - p)$. At the commencement of the evaporation, there was in the juice $(PC\ \theta)$ calories, and after the evaporation there remains $(P - p)\ C\ \theta$ calories.

The calories given off by the steam or vapour which is condensed, increased by those from the juice, must form a number equal to that of the calories which remain in the juice increased by those which are changed into steam or vapour, therefore as follows :—

$$(A + BT - \theta)\ q' + PC\ \theta = (A + B\ \theta)\ p + (P - p)\ C.\ \theta.$$

Thus— $$q' = \frac{p\ [A + (B - C)\theta]}{A + BT - \theta.}$$

Simplified gives—

$$q + q' = \frac{p\ [A + (B - C)\ \theta] + CP\ (\theta - t)}{A + BT - \theta}$$

That is the quantity of steam or vapour necessary in the first case to evaporate the weight P of water to a weight of juice equal to P, but that formula is not complete as the mention of time necessary to effect the operation is omitted. There are two causes which influence the duration of time, viz. :—

(*a.*) The nature of the surface to be heated.

(*b.*) The physical elements constituting the phenomena of heat, that is to say, the duration of the initial and final temperatures of the heating and the boiling, in short, the laws of Newton.

The nature of the heated surface influences the total of the condensed vapour, while the laws of boiling are only relative to q. So that q will be subjected to the combined influences of a and b. As far as q is concerned, the time which it requires to condense differs with the easiness of contact, therefore depends upon the nature of the surface to be heated.

a — the quantity of heat x given off by the surface in a given time, for example τ is expressed by the formula

$$x = \tau \frac{K}{e} (T - \theta) S, \text{ in which}$$

K=The co-efficient of the conducting power of the metal.
e=The thickness of the metal.
S=The heating surface.

Supposing—

$\tau = 1$ second.
$S = 1$ metre.
$T - \theta = 1$ degree. It gives $x = \frac{K}{e}$

The tubes of the apparatus are made of brass about 0·001 m/m thick, the co-efficient of conducting power of which is $K=69$, that is say, that the quantity of heat given off by a plate of one metre thick, the two planes of which are at a constant temperature of 69 calories per square metre per hour with a difference of 1° of temperature, thus the thickness of 0·001 m/m gives $x=69,000$ calories, which gives for the quantity of vapour or steam condensed on that surfacee $\frac{69,000}{650} = 106$ kilos, but this theoretical co-efficient is only admissible in the case when the juice which covers the two surfaces is renewed as

quickly as possible, (which is not found in practice), and varies greatly, according to the construction of the vessel, as it is not the same in a steam chamber with a double bottom, serpentine or tubes.

In the latter case it is generally admitted that one metre of heating surface will only condense 3 kilos of water per hour, per 1° higher temperature. This number will be adopted, but in practice it is found that in a Triple Effet it is often lower than 1°, and the calculation will be made supposing the machinery to be perfect, the result can be safely corrected afterwards.

Thus Q being the total quantity of vapour or steam condensed to evaporate p in the experimental conditions of the machinery, the heating surface sufficient for the tubular steam chamber will be $S = \frac{Q}{3\ (t - \theta)}$

b—The physical elements of work of the Multiple Effet apparatus are of two descriptions, as two phenomena have to be produced, the previous heating and then the boiling of the mass P.

The time necessary to heat P will be much greater as there is more heat to be produced, which is evident, and explains itself by the rapidity of the heating, being in inverse proportion to the excess of the temperature of the vapour for heating over the average temperature of the mass P before the evaporation. As to the boiling of P or the evaporation of p the rapidity of that phenomenon will be proportional to the excess of the temperature of the vapour heated over boiling point, following the laws of Newton, which is applicable to the case when the temperatures are not very high. As for instance $\left(\frac{t+\theta}{2}\right)$ the average temperature of the juice before it boils, we have for the heat given off by the vapour $\left(T - \frac{t+\theta}{2}\right)$ Suppose also that $(T - \theta)$ is the excess of temperature above that of the boiling juice, and if the time is taken into consideration, in a unit of time it is necessary to condense

$$Q = q' + \frac{T - \theta}{T - \frac{t+\theta}{2}} q.$$

giving q' and q the value which has been previously found, it is simplified by—

$$Q = \frac{p[A+(B-C)\,\theta]\,[T-\frac{t+\theta}{2}]+(T-\theta)\,(\theta-t)\,PC.}{(T+\frac{t+\theta}{2})\,(A+BT-\theta)}$$

This is the quantity of steam or vapour that is sufficient to evaporate p in units of time, under the conditions in which the engine works. To express the surface necessary to produce that work, there is,

$$S = \frac{P[A+(B-C)\theta]\,[T-\frac{t+\theta}{2}]+(T-\theta)\,(\theta-t)\,PC.}{3\,[T-\frac{t+\theta}{2}]\,(A+BT-\theta)\,(-\theta)}$$

This is not all, the tubular form of the steam chamber gives a condition which is indispensable, and must be introduced into the formula.

Each metre of heating surface is on the average, equal to a volume of 0h. 266, which gives a weight of juice equal to $0{\cdot}266 \times D$, D being equal to the corresponding density of the juice, and gives $P = S \times 0{\cdot}266 \times D$ expressed in hundreds of kilogrammes.

Substituting this value of P in the formula and making all necessary transformations, it gives definitely,

$$S = \frac{p\,[A+(B-C)\theta]\,[T-\frac{t+\theta}{2}]}{(T-\theta)\,[3\,(T-\frac{t+\theta}{2})\,(A+BT-\theta)-0{\cdot}266(\theta-t)\,DC]}$$

S is the surface expressed in metres per hectolitres of the juice treated.

THE SECOND CASE $\theta < t$.

The juice begins to boil, immediately losing some of its heat, which will be added to the heat of the vapour to obtain the evaporation of p.

P of the juice loses $P\,(t-\theta)\,C$ calories, corresponding to the evaporation of $P\,C\frac{t-\theta}{A+BT-\theta}$ kilogrammes of

water, there only remains to be evaporated

$$p - P\,C\,\frac{t-\theta}{A+BT-\theta}\text{ kilos of water.}$$

Suppose q' equals the quantity of steam or vapour necessary to be condensed to evaporate the preceding weight of water q' gives by condensing $(A+B\,T-\theta)\;q'$ calories, and the preceding weight of water by evaporation gives

$$(A+B\,\theta)\;(p-\frac{P\,C,\;(t-\theta)}{A+BT-\theta})\text{calories.}$$

There remains a weight of juice equal to $(P-p)$, the juice at the commencement of the evaporation contains $PC\;\theta$ calories, after which there remains $(P-p)\;C\;\theta$ calories, there is thus the same as in the first case,

$$(A+BT-\theta)\;q'+PC\;\theta=(A+B\,\theta)\;(p-\frac{PC\,(t-\theta)}{A+BT-\theta})+(P-p)\;C\;\theta$$

in which there is

$$q'=\frac{p\;[A+(B-C)\;\theta]\;(A+BT-\theta)-(A+B\;\theta)\;(t-\theta)\;PC.}{(A+BT-\theta)^2}$$

As to the time necessary for making this evaporation, the quantity of condensed vapour resumes itself in q', which it has been seen depends on the difference of the temperature of T and θ, the rapidity of the evaporation will be proportional to $(T\;\theta)$ and as $q'=q$ in this case, there is for the surface,

$$S=\frac{Q}{3\;(T-\theta)}$$

Then, $P=S.\;0{,}266\;D$. Thus :—

$$S=\frac{p\;[A+(B-C)\;\theta]\;[A+B\;T-\theta]}{3\;(A+B\;T-\theta)^2\;(T-\theta)+(A+B\;\theta)\;(t-\theta)\;0{\cdot}266\;D\;C.}$$

THE THIRD CASE $\theta=t$.

Is the same as given in the 1st and 2nd formulæ. The result of $\theta=t$, is :—

$$S=\frac{P\;[A+(B-C)\;\theta]}{3\;(T-\theta)\;(A+B\;T-\theta]}$$

APPLICATION OF THE FORMULÆ.

In the Multiple Effet apparatus which are used in sugar manufactories, the first tubular steam chamber is heated by the exhaust steam only from the engines in the factory, or with the assistance of direct steam. If the juice is supplied at a low temperature into the first vessel, the boiling point will be higher than the initial temperature, which will give a low vacuum. In the first tubular steam chamber there is the first case $\Theta > t$, the juice leaves the first vessel and enters the second at a temperature of Θ. The steam or vapour formed in the first vessel is also at Θ°, and passes into the tubular steam chamber of the second vessel to heat the juice which it contains, and is also at Θ°. Thus, in the second vessel the initial temperature of the juice, and that of the vapour are equal, $T=t$. But the vacuum in the second vessel being higher than in the first, the vapour produced escapes at a temperature lower than the initial temperature, which temperature the juice itself takes in this vessel, therefore $\Theta < t$ gives the second case. The same is repeated in the following vessels.

Looking at the formulæ or only the facts which they represent, it is evident that less steam is used in the first tubular steam chamber than in the second, so that the steam or vapour in the first vessel must be as near as possible to that in the others, which in practice means to admit the juice at as high a temperature as possible. Considering the most simple case, which is the third, to render Q as low as possible, the numerator must also be as low as possible and the denominator as high as possible, which is obtained by diminishing Θ or increasing T. But if Θ is diminished in one vessel, T is also diminished in the following vessel; also if T is increased in one vessel then Θ is increased in the next or following. There must be taken an impartial measure to equalize the temperatures in the different vessels, that is to say, to take the sum of the calories which can be given to all the vessels, and to divide them into as many equal parts as there are vessels, and modifying them according to the practical requirements of the engines, as may be seen in any particular case.

REMARK I.

It is desirable to know that the following are the specific heats agreeing to the different densities of the juice.

Density.	Specific Heat.
1·	1·
1·0685	0·9
1·1370	0·8
1·2055	0·7
1·2740	0·6
1·3425	0·5

The above are sufficient for the different cases which are to be considered, and as far as the composition of the juices may vary, from the year and the dates of work in the same year, an exact limit cannot be fixed for these numbers.

REMARK II.

These calculations are made on the supposition that P equals a certain weight of heat which becomes $(P—p)$ after the evaporation in the first vessel, $(P—p)$ enters into the second and becomes $(P—p—p')$ which passes into the third vessel, &c. In reality the apparatus does not work so; the juice is animated by a continuous movement, and the volume is steadfast in each vessel, but at the same time the change takes place in fractions of weight, whose sum is equal to P, and which is represented by the stream of juice which passes through the supply cock in a given time. This inference is not less just, as if there is a fraction of P $\frac{P}{n}$ it will give $\frac{p}{n}$ vapour or steam, and its volume is finally reduced to $\frac{P-p}{n}$, which will only contain $\frac{(P—p)\ C}{n}$ calories.

Repeating n times that influence every time the supply cock is opened and delivers a weight of juice equal to $\frac{P}{n}$ or such quantity as may be desired, the same result will be arrived at by considering the whole mass at once.

REMARK III.

The heating surface of the different steam chambers must be, as Péclet expresses it, in inverse ratio to the excesses of temperature. By the formulæ given it has been

proved, that the best conditions are those when the excesses of temperature are equal, so that the vessels are perceptibly the same except for the modifications arising from the changes in the density and specific heat, which will be considered later on.

Thus $S\ S'\ S''$ are the different surfaces, and $t\ t'\ t''\ t'''$ the temperatures of the heat

$$3\ S\ (t-t') = 3\ S'\ (t'-t'') = 3\ S''\ (t''-t''')$$

each number of the comparison representing the quantity of steam or vapour condensed in each vessel, which quantities are necessarily equal, giving $S = S' = S''$.

REMARK IV.

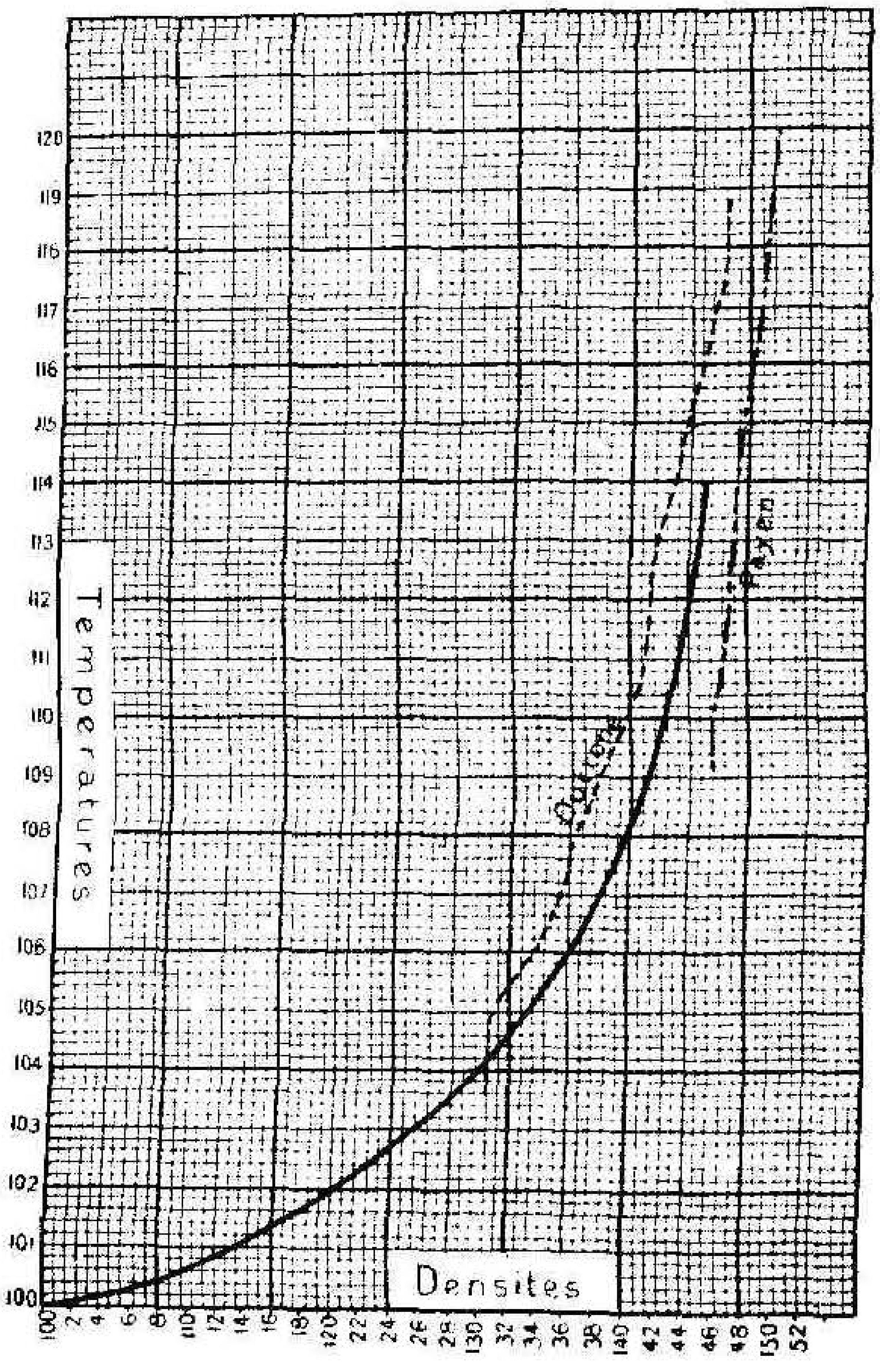
When the juice is evaporated by a constant source of heat, in proportion to the concentration of the liquid, more time is necessary for the evaporation. By an experiment made in the laboratory, it was found that 1 k.g. of juice, required 12 minutes to rise from 5° to 12° Beaumé, which is equal to the evaporation of 0·500 k.g. of water; 1 k.g. of juice required 14 minutes to rise from 12° to 24° Beaumé, making 0·500 k.g. as the amount of water evaporated. 1 k.g. of syrup requires 45 minutes 48 seconds to raise it from 24° to grain, making 0·570 k.g. of water evaporated. Many reasons concur in causing this increase of time in the evaporation, and amongst others the following. In proportion to the increase of the concentration of the juice the boiling temperature increases. For instance, water boils at 100°, juice with a density of 1·365 will boil at about 105°, and at 114° it will boil to grain. A diagram has been drawn out showing for each density, the corresponding boiling temperature. (diagram on page 80.)

Many authors, such as Payen and Dutrône, have already given some isolated numbers showing the boiling temperatures of the grain, Flourens giving the boiling point of the syrups. We have made the diagram complete up to the point at which the areometer stops.

At the moment when the syrup begins to crystalize by cooling, Payen gives it as the average boiling temperature. In the diagram is shown on each side, the lines of the temperatures given by Dutrône and Payen, this diagram is made from beet-root juice, by remelting masse cuite of the following composition :—

Sugar - - -	79·75
Glucose - -	0·18
Ash - - -	5·55
Water - - -	5·50
Unknown - -	9·02
	100·00

DIAGRAM
OF THE
BOILING TEMPERATURE AND DENSITY OF JUICE.



In juices charged with glucose, such as may be got from the remelting of cane sugar, containing much inverted sugar, shows itself to the right on the diagram, like Dutrône's, having a sudden deviation from about 100° to 102°. In fact the inverted sugar curve, which rises parallel with that of the pure sugar, shows great average deviations, which are caused by the nature of the sugar. It is here unnecessary to go into the theory of the causes of these deviations. The curve of the pure sugar which is in the higher temperature becomes lost in the curve in about 102° or 103°, a little towards the right.

REMARK V.

The general formula for the working of the vessels is given on page 74.

which is $S = \frac{Q}{3(T-\theta)}$ thus, $Q = S\,3\,(T-\theta)$.

Q being the quantity of vapour or steam condensed to evaporate a giving weight of juice, so that the apparatus may do the greatest possible amount of work, which is to say, that in order that the weight p of juice worked by the apparatus may be as great as possible; the value of Q must be increased to its maximum limit; the maximum of Q or of $S\,3\,(T-\theta)$ will be obtained when $(T-\theta)$ is as great as possible, since $(S\,3)$ is a constant. Then θ depends on the vacuum in the last vessel of the apparatus, T will vary with the pressure in the exhaust steam receiver. If we then make T as great as the working of the engines will permit, and θ as low as the best working vacuum can give, it will give Q as its greatest value.

There is still a variable quantity in this equation, it is the co-efficient 3 which differs with each apparatus. There are apparatus of which the co-efficient is 0·8. Mr. Rillieux allows in his apparatus 2·7, which is the highest figure that has been used or obtained, this entirely depends upon the construction of the apparatus being more or less good, the proportions being conformable to the parts, and upon the free circulation of the steam or vapour among the tubes of the steam chamber. If the apparatus is well proportioned it can be seen at once by the amount of work it performs, that is to say, the amount of juice it will treat per square metre of heating surface.

MULTIPLE EFFET APPARATUS.

The Multiple Effet apparatus are classed according to the number of vessels of which they consist, and are named Double, Triple, and Quadruple Effets, &c., when they have two, three, four, or more vessels, these numbers are not limited by theory, but in practice we should be guided by calculation of how much will be saved by buying or adding a supplementary vessel, looking at the saving in fuel as well as the dead capital which the apparatus represents.

Now will be taken into consideration the different apparatus for evaporating by Multiple Effet. We will first point out that if we have the same amount of heat, and the tubular steam chambers have the same heating surface, no one of these apparatus, whether it has two, three, four, or five steam chambers, would do more work than the other. In other words, if a Triple Effet had 300 square metres of heating surface, and each tubular steam chambers has 100 square metres, it will do the same amount of work as a Sixtuple Effet with the same heating surface, provided that the fall of the temperature between the steam and the vapour which arises from the last vessel be the same as each square metre of heating surface, will be itself subject in the two cases to the quantities of heat in inverse proportion to the number of vessels.

Only it is evident, that to produce the same amount of work there would be required six times less initial steam in a sixtuple Effet than in a simple Effet five times less to a quintuple; four times less to a quadruple Effet, and so on so that the economical relations of those apparatus are represented by the number of their vessels.

THE APPARATUS RILLIEUX.

Without following the phases which the Double and Triple Effet have passed through in the hands of its inventor, and as to the form of the vessel, it may be said that his apparatus of the present day is composed of horizontal tubular vessels, similar to those of a locomotive, each of the vessels being supported by four columns, the steam circulates in the interior of these

columns, which have a valve arrangement on the top, permitting the isolation of each or any part of the Triple Effet. The vessel which boils to grain has the same form as the others, only it contains half the number of tubes. The first vessel heats at the same time the second, and the vessel which boils to grain by means of vapour conductors which are completely concealed, so that not a single tube in the whole apparatus can be seen.

The same condenser and air pump serve for the last vessel and for that which boils to grain. The engine for this pump works the small pumps which are used for extracting the condensed water out of the second and third tubular steam chambers, and the exhaust steam is supplied direct to the first vessel without the use of an exhaust steam receiver.

Nothing is more simple than this installation, all the parts having been calculated and so arranged, that the man in charge, after the valves are once regulated, has only to inspect the progress of the operation.

Mr. Rillieux constructed a Double Effet for the Island of Cuba, where the juice is very dense, and the begass very dry, and a Triple Effet for Louisiana, where the juices are more diluted and the begass much damper, and not so good for fuel. These apparatus gave such good results that the manufacturer never required to use any other fuel than the begass.

The apparatus which is described in the "Patent Office Report" of 1848, is the same of which drawings and plans came into the hands of Tischbein, and afterwards of Cail & Co., but they did not understand that the last vessel was the vessel used for boiling to grain. And seeing a Double Effet apparatus with a Double Effet for boiling to grain, they thought they had got a Double Effet with three vessels, and that is the reason why they constructed a Double Effet provided with a central vessel flanked by two small side vessels, such as the first apparatus were made. They also believed themselves justified in saying that Mr. Rillieux had himself made a mistake, by calling a Double Effet with three vessels, a Triple Effet. Mr. Rillieux, however, has never said or written anything on the subject. The following is the gist of what the principal authors, who had made this class of apparatus their study, have to say.

Payen, in his "Traité de Chimie Industrielle" (5th edition, 2nd volume, page 256), says Messrs. Cail & Co., in perfecting an apparatus which was first used by Mr. Rillieux in America, have added the advantages of their first Double Effet apparatus to that which we have just described, making the operation still more economical.

Péclet, in his "Traité de la Chaleur," (4th edition, 2nd volume, paragraphs 1650 to 1655) after having given the design of a theoretical arrangement for a laboratory, otherwise very imperfect, which he says is right for the evaporation of juice in a vacuum (in his first edition, there was no mention about this, as the apparatus of Mr. Rillieux was not then known) asserts that vacuum need only be formed in the Triple Effet one or twice per day. Then in paragraph 1656 he writes :—The principle of successive distillations and evaporations, by using the same heat, seems to have been found out in 1834, by Mr. Pecqueur, after which apparatus were constructed on this principle by different constructors, especially in America by Mr. Rillieux in 1845—then he gives the description and lithograph of the Quintuplo Effet of Pecqueur. The fifth vessel of this apparatus boiled in the open air, in which, consequently the syrup would boil from 101° to 128°, and with steam at 132°. Juices exposed to such high temperatures would only give caramel, and the fact is that this Quintuple Effet which was protected by a patent in 1829, and of which the principles were known long before this date, succumbed at its birth.

To evaporate with a Multiple Effet in the open air is not good in practice. The object of Mr. Rillieux's patent, being to evaporate in a vacuum by a Multiple Effet, which presents conditions indispensable to obtain a rapid evaporation and at a sufficiently low temperature to prevent the sugar forming into caramel.

It appears that Péclet did not understand this. Lastly the Essays of Mr. Rillieux date from 1835, 1842, and 1843, and not from 1845.

Péclet, in paragraph 1657, describes an apparatus proposed, he says in 1849 by Pecqueur, and represented by Fig. 380, this arrangement is not very practical, and was one of the first contrivances, which Mr. Rillieux had tried in the United States in 1843. Péclet gives in paragraph 1660 a description of the apparatus Rillieux, and he goes

on to say, " as far as the system of operations is concerned, the patents of Mr. Pecqueur only contain ideas which are perfectly just, but the same cannot be said of those which were taken out afterwards.

Mr. Rillieux admitted that the surfaces for the condensation of the steam or vapour ought to be greatly increased in proportion to the distance from the first vessel, his apparatus consisted of three vessels, the vapour produced in the first was condensed at the same time in the two other vessels, it was evident that this effect could not take place unless the liquid in the two vessels boiled at the same temperature, notwithstanding Mr. Rillieux used liquids of different densities, so that the apparatus was in reality a Double Effet, and only a Triple Effet when the first vessel was supplied with exhaust steam from a high pressure engine and taking into account the effect of the vapour produced by the engine. Further on he says, the two last vessels being connected to the air pump by the same pipe produced the same elastic force, and the juices could only boil at the same temperature and with the same degree of concentration, after introducing the liquids at different densities. Nevertheless, according to the description, the second vessel could concentrate the juice to 25° and the third from 25° to masse cuite. It is evident from what has been said that Mr. Rillieux, the inventor of the apparatus, had not given his full attention to the physical phenomena which arise. Further he adds, that it seems to him that Pecqueur was the first who established the true principles of evaporation by Multiple Effet, and the first to apply them.

The result of this was, that Péclet, and Cail & Co. confounded the Double Effet with the Triple Effet, having only had the description of the first, which has been called here the second. Afterwards he accuses Mr. Rillieux of not understanding the working of his apparatus, when it was himself that did not exactly understand the working of the steam or vapour in the vessels; he did not see that the first vessel was a generator of vapour, the temperature of which was sufficiently high to boil the syrup to grain, at the same time heating the other vessels, and as he did not give himself the trouble to obtain information in the United States, or even in Cuba and Mexico, as to whether the apparatus worked or not, as indicated by the author; he exposed himself by finding

out great inaccuracies, which are contradicted by facts, he then makes an error in the dates of the patents of Mr. Rillieux and Pecqueur, the patents of Pecqueur being a later date than those of Mr. Rillieux.

It is not necessary here to discuss the Quintuple Effet apparatus working in the open air, which has nothing to do with the apparatus working with a vacuum.

Mr. Walkhoff in his "Traité de Fabrication de Sucre" (2nd edition, page 233), speaking of the condensers of Degrand and others similar, says: "that unfortunately contact with air exposes solutions of sugar to alterations, and that this drawback has condemned the use of all apparatus based on this principle.

Mr. Rillieux at this time had an idea which he first applied in America, that was to use the vapour arising from the juices to evaporate the other juices in a vacuum: then follows the description of the apparatus, in which he criticises the arrangement of the vapour pipes, believing that the steam or vapour is divided irregularly, and that the expulsion of the air from them is difficult; that it accumulates for the moment in a certain number of the tubes, which for that moment are lost to the action of the steam or vapour, and he supposes that the unequal expansion by this system caused the joints to leak, and that it will be difficult to clean, requiring the use of acids, which is bad, in consequence of the prejudical action which they exercise on the sugar.

Only facts can answer all these objections. In Louisiana the apparatus are cleaned after each crop, in Cuba once in the middle of the crop, and at the end.

As far as the use of acid is concerned it is well known that it offers no difficulty if followed by a very careful washing with a large quantity of pure water.

However, after seven years' use, the arrangement of the tubes has been modified, so that they can be removed from the vessel for cleaning without a leakage taking place in the joints.

As regards the air contained in the apparatus in which there is a continual current as in a locomotive, it does not as Mr. Walkhoff supposes remain there, it mixes with the steam or vapour, and however small the quantity (whatever M. Maumené writes in his "Traité de Fabrication de Sucre") it reduces considerably the velocity of

transmission of the heat, through or over the surface to be heated. It is thus that in a tubular steam boiler, in which the flame contains much air, the temperature of the flame being 1500°, the smoke 350°, giving in the chimney an interior pressure equal to 8 atmospheres, the mean fall of the temperature in the boiler being 755°, it does not transmit more heat through or over the surface to be heated than if the steam or vapour circulating in the tubes had a fall of temperature of 15° to 17°.

At the end of the preceding observations, Mr. Walkhoff repeating what Péclet says on the proportional increase of the heating surface, and attributing the supposition to the physicist, Mr. Rillieux, concludes that Mr. Rillieux has made another mistake in not considering the words of Péclet. Writers of books who copy their precedessors, without taking into account any calculations relying only on the good name of the author whom they imitate, would reproduce indefinitely the many mistakes which we have mentioned, we consider it our duty to enlighten them, at the same time deploring that a man so learned as Péclet, whose book is one of the rare works of merit and utility to science, has not looked further than the trials or experiments made by Cail, in order to assure himself of an apparatus so intricate as that of Rillieux. It is not necessary to consider any longer the original apparatus of Mr. Rillieux, as the calculations which follow and which are used for Mr. Rillieux's apparatus can also be used for any other. We will commence the study of the apparatus in general by that of the Triple Effet, which is most used in the sugar industry; then will be given the same apparatus boiling to grain as a Double Effet, which will complete the history of the Rillieux apparatus.

THE TRIPLE EFFET APPARATUS.

The firm of Cail & Co. constructed at first horizontal Triple Effets, according to the model of the Rillieux apparatus, and afterwards the vertical apparatus, (Fig. 82, Plate II.) having the same arrangement of valves and columns for the transmission of the vapours, and only differing from the first by the position of the vessels, but those apparatus were only Double Effets with three vessels. It is possible that these first vertical vessels were made from a rough sketch which was given to Brami Andraea by Mr. Rillieux, which were very easy to clean. The

trials or experiments to give the three vessels the action as a *Triple Effet* are due to Mr. Robert de Silovitz, doubtless to him also is due the use of the save-all placed at the side of the vessels. In the horizontal apparatus these save-alls existed, and were placed beneath the vessels, since which all constructors have imitated them, at the same time modifying them with slight improvements to suit the apparatus. The fault of all these apparatus was that the quantity of juice evaporated was very small in proportion to the large heating surface, that such poor results were obtained is attributed to the imperfect distribution of the steam or vapours in the tubular steam chamber of the vessels, since then the efforts of the constructors have been directed to this point. Cail & Co. placed parallel diaphragms in that part of the vessel in order to circulate the vapour successively, in and around all the tubes, and to those which are furthest away from the steam or vapour inlet, they give to these diaphragms a circular course, obliging the vapour or steam to circulate in that space or direction to the central pipe, other constructors thought of introducing the steam or vapour through a perforated pipe running round the inside of the tubular steam chamber, the same as Piedbœuf in Germany, and Séraphine of Paris. The firm Fives Lille expands the inside of the tubular steam chamber, (Fig. 87, Plate II.) which projects and circulates the steam or vapour entirely round the tubes, and penetrates by traversing a perforated plate which uniformly distributes it the full height of the tubes and chamber. This is all very good, but nobody has calculated if the vapour connecting pipes of the apparatus were in proportion to the quantity of steam or vapour which must pass through them to circulate round the tubes, or if the vapour exits were too large or too small, or if the condensation was such as to facilitate the circulation of the juice, it was thought to increase the circulation by putting into the centre of the tube plate a much larger tube. The above points had evidently not been taken into consideration by Cail & Co. when they made their first apparatus, as they would not work, and were named the *Triste Effets*, from the trouble they gave the manufacturers who used them, and at last they came to the idea of providing the vessels with pipes, after which they obtained a bad simple Effet with three vessels, which were of good construction.

Another idea originating with the constructors was to increase the dimensions of each succeeding vessel, the first being smaller than the two others, there was confidence in the reasoning of this, that the steam or vapour which heats the first vessel being of a higher temperature required less heating surface than the second, and more especially than the third vessel, which is heated by steam or vapour at a low temperature. This reasoning is not right, and has already been taken into account and proved by the formulæ already given. The Rillieux vessels were of equal sizes, and they should be so. The only reason which would support the adoption of the last vessel being larger is the question of incrustation; as a matter of fact, incrusted tubes being poor conductors of heat a much larger effective heating surface is required in order to do the same amount of work as if they were clean, and to allow for a certain accumulation of dirt and sediment, otherwise scale, therefore certain constructors have made the first two vessels of the same diameter, to work as the last vessel alternately, the one working while the other is being cleaned, so that the Effet is never stopped.

CALCULATIONS FOR THE HEATING SURFACE OF A TRIPLE EFFET.

These calculations will be based on an apparatus having a capacity of 4,000 hectolitres, for which is required the amount of effective heating surface in square metres for the evaporation of the juice to syrup, which contains 84% of water. The vapour or steam used for heating the first vessels will be taken as 110°, and the vapour which arises from the third vessel as 53°, so that the difference in the heat will be $110° — 53° = 57°$. The syrup boiling in the last vessel at 101·50°, in the second at 101°, and in the first at 100·50°. A fall of 3% of temperature of the steam or vapour to be divided equally between the vessel in such a way that the difference shall be $\frac{57° — 3°}{3°} = 18°$ for each vessel which gives in the formula $(t — t') = 18°$.

The initial temperature in the exhaust steam receiver is 110°, so that the temperature of vapour arising from each vessel will be as follows:—

From the 1st Vessel - - $91^{\circ}\cdot 50$
" " 2nd " - - $72^{\circ}\cdot 50$
" " 3rd " - - 53°.

At these temperatures how much vacuum is required to boil the water ?

At $91^{\circ}\cdot 50$ the tension of the vapour or steam is $55^{\circ}\cdot 60$ } Regnault.
" $72^{\circ}\cdot 50$ " " " " " " $25^{\circ}\cdot 96$ }
" 53°. " " " " " " $10^{\circ}\cdot 66$ }

The vacuum gauges on the different vessels will indicate 204, 500 and 654·4 millimetres, to all these elements must be added those which are relative to the average density of the liquids in the three vessels, the corresponding specific heat and the boiling temperature of the liquid, which gives the following Table.

No. of Vessels.	Depression.	Water evaporated.	Average Density.	Specific Heat.	Boiling Temperatures. Juices.	Boiling Temperatures. Water.
1	294	28	1·042	0·95	92·00	91·50
2	500	28	1·063	0·90	73·50	72·50
3	654·4	28	1·130	0·85	54·50	53·00

Supposing the volume of beet-root juice to be worked is represented by *100*, then all the necessary elements are given to apply the formula. For capacity the calculation is made in litres, heating surface in square metres per hour. For the three vessels we have the following data :—

	1st Vessel.	2nd Vessel.	3rd Vessel.
P....	28	28	28
T....	110	91·50	72·50
t....	80	92	73·50
θ....	92	73·50	54·50
D....	1·042	1·063	1·130
C....	0·95	0·90	0·85

In the first vessel $t<\theta$ this being the first case as has been seen elsewhere. We introduce these numbers into the formulæ, making—

$$S = \frac{28\,[606\cdot 5+(0\cdot 305-0\cdot 950)\,92]\,\left[110-\frac{82+92}{2}\right]}{(110-92)\,\left[2\left(110-\frac{80+92}{2}\right)(606\cdot 5+0\cdot 305\times 110-92)-0\cdot 266(92-80)1\cdot 042\times 095\right]}$$

$$S=0\cdot 777$$

The numerial 2 has been taken to represent the evaporation of a square metre of heating surface, but in reality it is more, as there can easily be obtained 2·5 and even 2·7 of the surface, which will thus be larger than is required for a given quantity of work, and is a good fault for practical calculations; 2·5 would give 0·620, instead of 0·777 which allows plenty of latitude, in the second and third vessels there is $t > \theta$ which gives the second case, using the formula there is found for these two vessels as follows :—

2nd Vessel $S = 0{\cdot}778$
3rd „ $S = 0{\cdot}780$

These surfaces represent those which are necessary to work off 100 litres per hour, or 166·6 hectolitres per hour for an apparatus of 4,000 hectolitres per day, of which the heating surface will be—

1st	Vessel	129·54	sq. metres.
2nd	„	129·61	„
3rd	„	129·94	„

It will be seen that there is a slight increase from the 1st to the 3rd in the sq. metres of surface, but far from 13 to 14%, which constructors generally adopt, admitting that certain parts of the tubes forming the heating surface do not get heated, being due to the presence of ammoniacal gases or other causes; each vessel is given 130 square metres of heating surface, which will always be more than is actually required, thus a total heating surface of 390 square metres. In all these calculations the Triple Effet is taken as being in the worst condition, only condensing two kilogrammes per square metre of heating surface, low pressure in the exhaust steam receiver, a moderate vacuum, and a heating surface very much less than is generally given to an apparatus of 4,000 hectolitres. Still the concentration of the juice has been brought further than is generally done.

In Cail & Co's. series, it is found that a Triple Effet with a capacity of 4,000 hectolitres has 469 square metres of heating surface, there is thus a difference of about 17% between the two surfaces. An apparatus having 390 square metres of heating surface can always work off at least 4000 hectclitres of juice, if it does not, the fault must be ascribed to an error in the construction.

If there is allowed for a Triple Effet of 4,000 hectolitres 2·5 as conducting power, and the pressure of the steam is only half atmosphere in the exhaust steam receiver, the temperature of the steam or vapour of the third vessel is 50°, this will give a heating surface of 250 square metres instead of 390, which is to say, that an apparatus having 64/100 of the presumed heating surface would do the same amount of work as the other in these new conditions, from which will be seen the importance of making the apparatus as perfect as possible, and to calculate all parts, so that there is no loss of useful heat, or surface left unheated.

It is not necessary to search further for the imperfections of the Triple Effet or other apparatus of this class.

In finishing this description, attention is drawn particularly to the proportions that are given to the different functional parts of this evaporating apparatus, so that in constructing a Triple Effet, of whatever capacity, these functional parts must be in correct proportions.

CALCULATIONS FOR THE DIMENSIONS OF A TRIPLE EFFET APPARATUS.

In designing a Triple Effet special care must be taken that the steam or vapour has a good circulation round all the tubes in the tubular steam chambers of the different vessels, also that the steam or vapour generated by the juice under evaporation is drawn off this vessel as quickly as possible, and with regularity, these points should be carefully looked into. When designing a steam engine, the steam ports should be as free as possible and the exhaust very large.

In a vessel of a Triple Effet, the greatest possible quantity of steam or vapour should be produced, and condensed as rapidly as possible, either in the tubular steam chamber of the following vessel, acting as a surface condenser, or in the condenser at the end of the apparatus. The quicker the condensation is in the tubular steam chamber of the following vessel the greater will be the evaporation and production of vapour from the juice under treatment. To effect this, the vapour connecting pipes from the top of the vessel and connected with the tubular steam chamber of the next vessel must be made as large as

possible to reduce the friction of the vapour passing through them to a minimum, and the condensation in the apparatus doing its duty the same as a condenser of a low pressure engine. To obtain this effect, the calculations mentioned have been looked for and made.

Our examples are taken from an ordinary Triple Effet, having a capacity of 4,000 hectolitres of juice in 24 hours, from which must be evaporated 84% of water, each vessel having 130 square metres of heating surface. From the 400,000 litres, there will have to be evaporated 336,000 kilogrammes of water in 24 hours, or 14,000 kilos per hour, which will give for each vessel to evaporate 4,667 kilos per hour, or about 1·3 kilos of water per second.

The temperatures in the different vessels of the apparatus being, 110° in the exhaust steam receiver, 91°·5 in the first vessel, 72°·5 in the second, and 53° in the third, under the corresponding pressures, one kilo of steam or vapour will be equal to, viz. :—

Exhaust Steam Receiver	1·257 ltrs. × 1·3 kls. will be=	1·634 lts.
1st Vessel - -	2·265 ,, ,, ,, ,, ,, ,,	2·944 ,,
2nd Vessel - -	4·715 ,, ,, ,, ,, ,, ,,	6·130 ,,
3rd Vessel - -	10·958 ,, ,, ,, ,, ,, ,,	14·245 ,,

It is here not necessary to try and modify the general designs of the apparatus, but only to calculate the dimensions of the pipes in general, taking the average velocity of the steam or vapour in the connecting pipes at 30 metres, and of the juice at 3 metres per second.

VAPOUR CONNECTING PIPES.

In calculating the dimensions of these pipes, the bends and friction must be taken into consideration, the velocity of the vapour should be less than 30 metres per second, our calculations will be based on 20 and 25 metres per second, in order that the areas may be sufficient in case it was wished to work the Triple Effet at an increased vacuum. When the quantity of steam or vapour produced in one vessel is known, also the area of the vapour connecting pipes for carrying off the vapour, the velocity of the vapour is found by using the following formula (No. 1) :—

$$v = \frac{Q}{S \times m} \text{ in which}$$

Q=The volume in litres of the vapour passing through the connecting pipes per second.

S=The area of the vapour connecting pipes, expressed in square decimetres.

v=The real velocity of the vapour passing through the connecting pipes expressed in decimetres.

m=The co-efficient of which the apparent value is 0·8.

The steam or vapour while passing through the connecting pipes loses a certain amount of its pressure or effect by friction, which is expressed by using the following formula (No. 2):—

$$P - p = p\,\frac{KL}{D}$$

Thus $\frac{p}{P} = \frac{1}{1+\frac{KL}{D}}$ Then, $\frac{p}{P} = \frac{v^2}{V^2}$ *Therefore* $\frac{v^2}{V^2} = \frac{1}{1+\frac{KL}{D}}$

No. 3. Then, $v = V\sqrt{\frac{1}{1+\frac{KL}{D}}}$

In these formulas—

P=The excess of pressure in the vessel over the pressure of the following vessel, or over the atmospheric pressure on the last vessel, is expressed by deducting 76 c/m from the number indicated by the vacuum gauge which is expressed in centimetres.

p=The pressure which should correspond to the real velocity of the vapour v, if there was no friction (in centimetres). By reducing p 76 c/m we would have the vacuum which the gauge would indicate if there was no friction.

v=The real velocity of the vapour as per formula No. 1, but expressed in metres.

V=The theoretical velocity.

L and D=The length and diameter of the steam or vapour connecting pipes.

K=0·024 (constant) co-efficient of the friction.

$P-p$=The loss of the pressure.

The formula No. 1 may also be expressed as follows:—

$$Q = m \times S \times v$$

Then v can be expressed by the formula $v = \sqrt{2\,g\,h\frac{\delta}{\delta'}}$ in which the pressure is expressed by $h \times \frac{\delta}{\delta'}$ in a column of vapour equivalent to the column of mercury indicated by the gauge, δ being the density of the mercury, 13·6 and δ' the density of the vapour in proportion to water, thus giving formula No. 4.

$$Q = m\,S\,\sqrt{2\,g\,h\frac{\delta}{\delta'}}$$

In the application of these formulæ, the value of Q is known, from which must be deducted the area S of the vapour connecting pipes, taking the velocity of the vapour as 25 metres per second. For example, supposing in formula No. 1, v = 25, then in formula No. 3, V will be equal to 25; according to this, the value of S in that formula is wrong, S being much too small. The following comparison will have to be made, giving S its value as $\frac{D^2}{4}$ and give v in formula No. 1 its value as in formula No. 3.

$$V\sqrt{\frac{1}{1+\frac{KL}{D}}} = \frac{Q}{\frac{\pi\,D^2}{4}\,m} \quad \text{which gives}$$

$$Q = \frac{\pi\,m}{4}\sqrt{\frac{v^2\,D^5}{D+KL}} \quad \text{Formula No. 5.}$$

$$\text{And } D = \sqrt[5]{\frac{16\,Q^2\,(D \times KL)}{\pi^2\,m^2\,v^2}} \quad \text{Formula No. 6.}$$

These comparisons being too complicated, they can be simplified as follows:—Suppose v=25 in formula No. 1, then from it is derived the value of S and D, substitute this value of D in the equation in formula No. 3, in which V will be equal to 25, from this will be obtained a new value of v, and may be used in formula No. 1, from which is found for S a sufficiently approximate value. If the formula No. 6 is made use of the same must be done. Supposing D=1 under the radical and an approximate value of D is found, and also placed under the radical. The new value of D will be sufficiently near for our calculations. If the steam or vapour connecting pipes have bends, formula No 3 becomes, viz.:—

Formula No. 7.

$$v = V\sqrt{\frac{1}{1 + A + \frac{K\,L}{D} + n\ \text{Sine}^2\,i}}$$

A is the co-efficient pressure which is due to the contraction of the steam or vapour at the entrance of the connecting pipes. When the pipe through which the vapour passes is of *uncertain* dimensions and length, this must be taken *into consideration*, when A can be used as a cipher, n the number of bends, and i their angle. Supposing the angles to be right angles, Sine $^2 i = 1$ which gives—

Formula No. 8.

$$v = V\sqrt{\frac{1}{1 + \frac{K\,L}{D} + n}}$$

If the angle of the bend is very acute, it is found that the resistance is double that of a right angle, so that the following formula No. 9 must be used, viz. :—

$$v = V\sqrt{\frac{1}{1 + \frac{K\,L}{D} + 2\,n}}$$

The resistance of a right angle bend is equal to half that of a right angle without a bend, so that a half circle bend gives a resistance equal to the half of two right angles. Taking a Triple Effet having a capacity of 400,000 litres and of the ordinary dimensions, there will be—

From centre to centre of vessels	- 2 m.	50 c/m.
,, ,, of 3rd vessel to centre of save-all	- 2 ,,	60 ,,
,, ,, ,, 1st & 2nd ,,	- 1 ,,	80 ,,
,, ,, ,, vapour connecting pipes to top of platform	- 2 ,,	85 ,,
,, floor of platform to centre of pump	2 ,,	50 ,,

Now will be calculated the dimension of the connecting pipe between the exhaust steam receiver, and the steam chamber of the first vessel; this pipe can be taken as one metre long, and having two round bends, counting the valve as one round bend, if it is of good construction and design.

According to formula No. 1, we shall have for the area of the pipe : knowing the volume of the steam or vapour as equal to 1,634 litres, and the velocity as equal to 20 metres per second or 200 decimetres, then :—

$$200 = \frac{1{\cdot}634}{S \times 0{\cdot}8} \qquad S = \frac{1{,}634}{200 \times 0{\cdot}8} = 10{\cdot}21$$

from which $D = 0{\cdot}36$, but in this pipe there are two bends (round), by introducing the value of D into formula No 8, it gives the following :—

$$v = 20 \sqrt{\frac{1}{1 + \frac{0{\cdot}024 \times 1}{0{\cdot}36} + \frac{2}{2}}} = 12{\cdot}2$$

By substituting this value 12·2 in the first formula, it gives the last diameter of the connecting pipe as—

$$12{\cdot}2 = \frac{1{,}634}{S \times 0{\cdot}8} \quad S = \frac{1{,}634}{12{\cdot}2 \times 0{\cdot}8} = 0{\cdot}1676$$

$$D = 0^{m}\,41$$

That number being greater than is generally adopted, we have tried to find in the steam engine some similar part to which a comparison could be made. In the steam engine as used in the navy, also in large single engines, all of the low pressure type, the exhaust steam is about the same pressure as that in the exhaust steam receiver of a Triple Effet which is carried through a connecting pipe, that is generally made too small for the quantity of steam or vapour that has to pass through it as 0·12 is to 0·13, equal to about 40 c/m diameter. This agrees with the calculations made, and after long experience and practice, adopted in the engines of the navy, and there is every reason to believe that this is right, and that the French constructors of the Triple Effet have made the pipes for supplying the steam into the first tubular steam chamber from the exhaust steam receiver much too small.

In calculating the diameter of the steam or vapour connecting pipes between the first and second vessels, we find as follows :—

$$200 = \frac{2944}{S \times 0{\cdot}8} \quad S = \frac{2944}{200 \times 0{\cdot}8} = 18{\cdot}40. \quad D = 0{\cdot}48 \text{ c/m.}$$

$$V = 20 \sqrt{\frac{1}{1 + \frac{0{\cdot}024 \times 4{\cdot}50}{0{\cdot}48} + 1}} = 15$$

The same formula is applied as for the preceding pipe, because there is a round bend or angle when leaving the

vessel, a right angle may be assimilated to a round angle at the bottom of the save-all, as to the entrance into the save-all; if this is of good construction, that is to say, of large dimensions, we need not take it strictly into account.

If the value of $r = 15$ was substituted in the first formula, it would give

$$150 = \frac{2944}{S \times 0{\cdot}8} \quad S = \frac{2944}{150 \times 0{\cdot}8} = 0{\cdot}2453 \quad D = 0{\cdot}56 \text{ c/m.}$$

If the same calculation was made for the passage of the vapour from the 1st to the 2nd vessel, and from the 2nd to the 3rd vessel, adopting 20 metres per second as the *normal velocity, much larger dimensions* would be the result, and experiments made with different gases seem to prove that the velocity of these gases was in inverse proportion to the square root of the density of the gases employed, it is thus natural, as the volume of the vapour which passes from one vessel to the other expands, that the area of the connecting pipes must be increased, according to which the dimensions of the vapour connecting pipes would be enormous.

To make sure that the above was correct, experiments were made on a Triple Effet, of which the connecting pipes were of rather a small area, but sufficient for the three vessels, and it was found that the loss of pressure or effect which the vapour experiences by friction in passing through the connecting pipes from one vessel to another, and from the last to the condenser, was the same for all three vessels, and that notwithstanding the change in the volume of the steam or vapour, while passing from the 2nd to the 3rd vessel, did not suffer more from friction than from the 1st to the 2nd vessels, so that the conclusion is, that the areas of all the vapour connecting pipes between the three vessels can be the same if they are of the same length, and that we may concede to without objections, velocities greater than 20 metres per second, for rarefied vapours without experiencing any sensible loss of pressure. If in the second vessel velocities are adopted *from 30 to 35 metres per second, and of 50 to 55* in the third vessel, these velocities will give the diameter of the vapour connecting pipes as 70 c/m which is quite sufficient.

There is still one point to consider, and that is when direct steam is obliged to be used for heating the Triple

Effet, the direct steam pipe must have an area and diameter, viz. :—

$$S = 0{\cdot}0260 \text{ and } D = 0{\cdot}18 \text{ c/m.}$$

This dimension is the same as Cail & Co. adopt to supply the same volume of steam to the Crampton Locomotives, which proves the exactitude of our formula.

CALCULATIONS
OF THE
AIR PUMP AND CONDENSER.

The air pump has to discharge from the Triple Effet the following :—

1st. The vapour condensed from the 3rd vessel.
2nd. The injection water.
3rd. The condensed water from the vapours, out of the 2nd or 3rd tubular steam chambers, if there are no special pumps for it.
4th. The air contained in the injection water which is $\frac{1}{20}$ of the water
5th. The air contained in the evaporating juice which is $\frac{1}{20}$ of the juice.
6th. The air contained in the vacuum of the vessels and the condenser.

The injection water necessary for condensing the steam or vapour produced in the Triple Effet, is calculated by the following formula—(Morin.)

$$P = \frac{p\,(550 + T - T')}{T' - T''} \text{ in which}$$

P = The weight of water necessary for the condensation.
p = The weight of vapour to be condensed.
T = The temperature of the vapour to be condensed.
T' = The ,, of the water in the condenser.
T'' = The ,, of the injection water.

In an apparatus of 4,000 hectolitres—

$p = 1{\cdot}3$ kilos.
$T = 50^\circ$
$T' = 55^\circ$ (4 or 5 degrees more than the vapour.)
$T'' = 10^\circ$ (the water is generally under this temperature.)

$$P = \frac{1{\cdot}3\,(550 + 50 - 55)}{55 - 10} = 15{\cdot}63$$

This quantity is a *minimum*, as the vapours from the apparatus are not pure, and contain uncondensable gases, air and carbonic acid, which are all difficulties in the way of a good *condensation*, *in consequence* of which at least double this quantity of injection water will be required, say 30 kilos per second. So that the air pump will have to discharge—

		Litres.
1st.	Condensed vapours from the 3rd vessel - -	1·30
2nd.	The *injection* water - - - -	30·00
3rd.	The condensed vapours of the 2nd & 3rd vessel	0·04
4th.	The air in the injection water = $\frac{1}{20}$ - -	1·50
5th.	The air of the *total juice* $\frac{1}{20}$ of 4·63 - -	0·23
6th.	The air contained in the vacuum by return memory	
	Total litres	33·07

In the event of the air pump forming an imperfect vacuum, which often proves to be the case, the steam engine must be referred to for the dimensions usually adopted, for which the following rule is sometimes used, viz. :—That the air pump must have a capacity equal to eight times the quantity of injection used, if that quantity was adopted, the volume developed by the pump would be 260 litres per second, and at 40 strokes per minute, would have a capacity of 340 litres, which is rarely exceeded, a pump 700 m/m dia. × 800 m/m stroke has a capacity of 300 litres per second, which quantity is very much larger than is used in the *French Triple Effets.*

To verify the preceding rule we have referred to the most modern steam engines, which were exhibited at the Universal Exhibition of 1878, in which the air pump of a Double Effet had an average volume or capacity of 0·136 of *the steam cylinder, and the pumps of* a Simple Effet 0·201 of the steam cylinder.

It is very difficult to understand why a single-acting pump of the Simple Effet has not double the active volume of the pump of a Double Effet, which proves that conjectures have always been the guide in such matters, and it may be remarked that constructors find that the Simple Effet pumps are more effective than the others, which *probably explains their lesser relative dimensions.* In taking 0·136 as the basis for a Double Effet pump, and comparing it with the evaporating apparatus, it will be

observed that the 1·3 kilos of vapour, from the 3rd vessel, at a temperature of 105°, will represent about 1,800 litres.

If the steam engine cylinder gives to the condenser 1,800 litres of exhaust steam per second at 105°, the air pump will have to discharge 244·8 litres, and if it makes 40 strokes per minute, it will have a capacity equal to 368·2 litres, that is to say a number higher, and similar to that which is found above.

The smaller dimensions which have been observed in the steam engine, give 271 litres of exhaust steam to the condenser, and the larger, an Austrian Engine 448 litres. This is for a Triple Effet 11 to 14 times the volume or amount of injection water per second, for which the pumps must have capacity for. In most cases the pumps supplied by constructors have only half this capacity, which is the cause of the low vacuum, so that a Triple Effet having a capacity of 4,000 hectolitres, should have a pump of 400 litres capacity, or one which has sufficient speed to develop the same volume.

The Condenser is a receiver in which the steam or vapour comes into direct contact with the injection water, its capacity should be large enough to allow the fountain of injection water to develop itself, and the steam or vapour on entering the condenser has its velocity retarded, and permitting the injection water to do its effective duty. The diameter of the condenser must be greater than the vapour connecting pipe, what the actual capacity of must be is difficult to determine.

The condenser of a steam engine is generally made a quarter of the capacity of the steam cylinder, if this is taken as a basis, then quarter of the volume of vapour arising or produced has to be condensed. The vapour to be condensed from the 3rd vessel is 14,245 litres per second, so that if the pump makes 40 strokes per minute it will draw off the water from 19,000 litres of vapour, of which the quarter is 4·75 cubic metres. This is rather too much. If 1,634 litres is taken as the volume of the vapour, at the pressure in the exhaust steam receiver, the capacity of the condenser will be 680 litres, on the other hand, this is not sufficient, by taking as the basis the air pump to the condenser of an engine, it is clear that the condenser must be double the capacity of the air pump, this would give a capacity of 800 litres, more than this is

preferred, and experience has proved that the condenser should have a capacity of from 1,000 to 1,200 litres, being three times the capacity of the air pump, which is the basis that will be adopted.

If the condenser is taken as being 1 metre diam. $\times 1^{m}\cdot 273$ high, its capacity will be one cubic metre, these dimensions will allow of 30 metres of injection water spreading itself.

There is one reason which should determine the use of large condensers; the injection water always contains about [illegible] of dissolved air, and further, if it is calcareous, it will always contain a certain quantity of carbonic acid, which frees itself under the influence of the heat and vacuum. If air only is taken into consideration, 30 litres of water will contain 1·5 litres at the atmospheric pressure or under a pressure of 1/8·6 of an atmosphere, $1\cdot 5 \times 8\cdot 6 =$ 12·90 litres. The elastic force of the air is equal to that of the vapour, and when added, this volume becomes about 15 litres, taking into account the temperature, or half of the water from which it arises.

The ammonical gases from the different vessels which escape into the condenser, can be taken at 10 litres, and this with the air which arises from the juice, will give a total of 30 litres of vapour, which is spread over the condenser per second, and is uncondensable; so that there is given to the condenser a volume equal to 300 litres, in which the water and vapour not condensable, will occupy a volume equal to 60 litres, or 1/5 of the total volume. If the condenser had a capacity or volume of 1,000 litres, the incondensable vapours would be divided over a space three times larger, so that their pernicious influence on the condensation would be three times less, therefore the condensers should be made as large as possible.

From the above, it will be seen how difficult it is to determine the capacity of the condenser, and we admit that it should be made, to have three times the capacity or volume of the air pump.

The injection water pipe to the condenser should be of such a diameter that the water flows with a velocity sufficient to form a fountain reaching to the top of the condenser.

To calculate the required velocity of the injection water, the following formula must be used :—

$$Q = K\,S\,v = \frac{\pi D^2}{4}\,K\,v \quad \text{in which}$$

Q=The effective discharge of water at the pipe opening.
S=The area of the pipe.
D=The diameter of the pipe in decimetres.
v=The mean velocity of the liquid.
K=A co-efficient of the quantity of water delivered by the pipe.

The co-efficient K depends on the pressure of the water and the diameter of the pipe, by referring to the tables drawn up for this purpose the value of K will be found. If we commence to determine the area of the discharge opening without knowing the velocity of the water the value of K will not be found, except by using the following formula :—

$$30 = \frac{\pi D^2}{4} \times K \times v$$

Then $v = \sqrt{2\,g.\,h.\,\frac{\delta}{\delta'}}$ and h equals 10 metres, height of the barometrical column, reduced by the height or distance of the condenser from the surface of the water in the well, if that height is 5 metres h is equal to 5 metres, because $\frac{\delta}{\delta'}=1$, $v=36\cdot5$; and substituting K by 0·60 it gives —

$$30 = \frac{\pi D^2}{4} \times 0\cdot60 \times 36\cdot5 \quad \text{In which } D =$$

0·153, and S=0·018385.

In the steam engine it is found that 1·3 kilos of steam or vapour has to be condensed, thus S = 0·01309 the agreeing number. The area of the injection pipe opening is regulated by a cone, sprayer, or perforated pipe, which should be the same as the pipe, and decides the discharge of the water Q, by a co-efficient equal to K, the main injection water pipe should be larger than the injection pipe in the condenser.

JUICE SUPPLY PIPES OF THE TRIPLE EFFET.

In this pipe the juice should travel slowly, say with a maximum velocity of three metres, the quantity of juice

passing through this pipe will be 4·63 litres per second, and its diameter will be found from the following formula:—$Q=\frac{\pi D^2}{4} K v$, in which K is equal to 0·6, gives—

$$4·63=\frac{\pi D^2}{4}\times 0·6\times 3$$

giving $S=0·0257$, and $D=0^{m}·180$. This pipe cannot be made too large, as the supply of juice is regulated by a pump, cock, or valve on the apparatus. For the other pipes, smaller dimensions can be used, or the same diameter.

DIVERSE PIPES.

The same formulæ and calculations can be taken for all the other pipes, such as the condensed water, ammoniacal gases, &c, which it is unnecessary to work out in detail here.

All pipes for steam or vapour, as in good designed steam engines, should be of large diameter, so that the *friction has no influence*, and *part* of the motive power is not absorbed by contractions, which is the case in most Triple Effets, large outlets should be adopted for the steam or vapour, particularly for the Triple Effet, which is the most intricate apparatus in all factories.

TRIPLE EFFET APPARATUS

Or a Double Effet for boiling to masse cuite in the third vessel.

It has been stated that in all Rillieux's apparatus in America, the boiling to masse cuite is done by a Double Effet.

Now take into consideration the Triple Effet with 4,000 hectolitres capacity, in which the fall is 18° for each vessel, and the temperature of the steam or vapour is —

110° in the exhaust steam receiver.
91·5° „ 1st Vessel
72·5° „ 2nd „
53° „ 3rd „

Supposing that next to the Effet, there was a vessel for boiling to grain, in which the vapour or steam has a temperature of 50°, by consulting the diagram on page 80, it will be seen that the syrup when it becomes masse cuite boils at 14° above the temperature of boiling

water, the syrup having a temperature of $50°+14°=64°$, and it being admitted that at the commencement of boiling the syrup to masse cuite, the temperature of the steam or vapour is 65°, will give 79° for the evaporation to masse cuite.

If the vapour arising from the first vessel is used for the boiling to masse cuite, there will be a fall in the first case of $91·5°—64°=27·5°$, and in the second case of $91·5°—79=12·5°$, the first vessel giving sufficient steam or vapour to finish the boiling to masse cuite.

There is but one remark to make about the vessels of Rillieux's apparatus for boiling to grain, that they are horizontal the same as the evaporating apparatus.

In Europe they are vertical, and it is not unusual to see the boiling mass at a height of 1m. 50 c/m. above the top serpentine.

The liquid having a density of 1·5°, a column of it $1·50^{m.}$ high corresponds to a column of water $2·25^{m.}$, that is to say at $\frac{1}{4·44}$ of an atmosphere exercises a pressure on the serpentine, which the steam or vapour must penetrate to rise to the top of the boiling mass, requiring an excess of temperature equal to 22°·5, necessary to boil the mass, so that the temperature in the lower part of the mass is $64°+22°·5=86°·5$. The vertical form of the vessel is a great difficulty, when the centre calender or belt is a great height, and the difficulty is to raise the temperature of the mass by artificial means; and secondly, the time to complete a boiling or strike is sometimes limited in a factory, if low pressure steam is used, and the density of syrup low, it will require a large heating surface to boil quickly. In the apparatus Rillieux, the heating surface of the vessel which boils to masse cuite is equal to the half or three quarters of that of each of the other vessels. These proportions are easily obtained with vertical vessels, having 4 serpentines, with a small heating surface the syrup must be of a high density in order to boil off in the same time.

From the time the Double Effet is used to boil to masse cuite the first vessel has to supply 1/5 more steam or vapour, than if evaporating by Multiple Effet did not exist, in consequence of which the reduction of the steam or vapour between the exhaust steam receiver and the first vessel will be 1/5 greater than between the following vessels, instead of being equal.

DOUBLE EFFET FOR MASSE CUITE AND EVAPORATION.

In a Double *Effet the* fall of density between each vessel will be from the same point as in a Triple Effet, $\frac{54}{2} = 27°$, so that the steam or vapour escaping from the 1st vessel will be 82°, and the boiling with Double Effet can be effected as in the preceding case, at the same time there should be taken into consideration the area of the heating surface, the fall of the density of the juice in the first vessel, and that the boiling point is lower.

OTHER ARRANGEMENTS.

The temperature of *the steam or vapour of the first* vessel of a Triple Effet is higher than in the Double Effet. It will naturally be still higher in a Quadruple Effet, and higher again in a Quintuple Effet. According to which, boiling to masse cuite can be carried out in a Quadruple Effet with the steam or vapour from the second vessel, becoming a Triple Effet, or in a Quintuple Effet, with the steam or vapour of the third vessel, a Quadruple Effet. All these arrangements result in economy of steam or vapour, in boiling to masse cuite, which economy is calculated by the number of vessels boiling to masse cuite.

Is is not necessary here to *numerate the different* Multiple Effet apparatus, of which the arrangements vary very much, at the same time it will be necessary to make in *each or for each apparatus, calculations similar to these* which have been given in this treatise, so that the *chief of a* factory can convince himself of the higher or lower degree *of perfection of his apparatus*, of which he can assure himself by inspecting the different gauges, and seeing if they work regularly or not; with that purpose this has been written, having *the* data, calculations can be made without any doubt whatever of the dimensions required for a Triple Effet by reducing all found areas, to those for an apparatus having a capacity of 1,000 hectolitres, and increasing these areas proportionately to the required capacity of the apparatus.

By the application or use of these numbers, the errors of many constructors have been revealed, especially

in respect to the areas of the vapour connecting pipes between the different vessels, which for the greater part are much too small, and in which the steam or vapour sometimes flows at the velocity of more than 100 metres per second. It is thus necessary to increase these areas, and to use larger air pumps with condensers in proportion, all things which have never been sufficiently studied.

It is still a question whether the vessels have to be made vertical as in France, or horizontal, the same as those of Mr. Rillieux.

The former are perhaps easier to clean, the second more favourable for the use of heat, but occupy more space in the factory, both constructions are good, so that it cannot be determined until comparative trials have been made. In Germany and Austria they are made horizontal and work well.

In conclusion it may be as well to mention that all these calculations are from experiments made by Mr. Rillieux fifty years ago, for the construction and establishment of his first apparatus—since which all has been modified, without again going over any of his calculations. Thus the European apparatus were put to one side in principle, whilst those of Mr. Rillieux were immediately adopted, and without question. May this example cause the constructors to leave off the method of guessing, and to adopt that of calculating, and may these pages facilitate their researches as well as those of the sugar manufacturers.

ESSAY

ON THE

CONSTRUCTION

OF

EVAPORATING APPARATUS

AND ITS

WORKING IN SUGAR FACTORIES

BY

HUGO JELINEK,

PRAGUE.

If we refer to "Péclet's Treatise on Heat, and its application in the Arts and Manufacture," (2nd volume, chapter 8 of the 9th Book,) we shall find the same, entitled as follows :—

EVAPORATING APPARATUS,*

in which the heat is used several times.

This chapter has for Sugar Manufacturers and Constructors of Evaporating Plants for Sugar Factories such a value that I quote the same.

The following will in a manner be a continuation of the ideas set forth in the above chapter and carrying them into execution, therefore, such of my readers as may have read this must not be annoyed. I may remark that this chapter was written more than 25 years since, and after having read it, we ask what advance has been made during that time, in the construction of Evaporating Apparatus as described, we must confess that it is insignificant, nay, I can assert with truth that the construction of these for sugar factories during that time has not only made no progress, but rather taken a step backwards. In the separate paragraphs of the chapter which I have

* Mr. Jelinek in his Essay gives the whole of this chapter, as I had the kind permision of the Publisher of "Péclet's Treatise" to translate it for this work, I did not think it necessary to reproduce it here.

referred to, mention is made of two, three and five vessels which have been employed in the evaporation of juice, and in part also altered for the application of the same steam two, three, four and five times.

If we look at our sugar factories, we will observe that it is by the merest chance we find an apparatus with three vessels, whilst four and as far as five appear merely as a devout wish in our provincial journals. In the last few years there as been a marked endeavour to erect evaporating apparatus for the multiple use of steam.*

In many factories they had tried to evaporate in the 2nd and 3rd vessels by means of exhaust steam, but this is all, as most of them gave it up, because the exhaust steam failed, which we shall see later, was sure to be the case, and they were compelled to use direct steam for the evaporation of the juice.

To reduce the consumption of direct steam, in the Austrian sugar factories they applied the diffusion process, which left nothing further to be desired than to produce high grade beet juice, and to work off and evaporate as much as possible, to attain this a quick evaporating is required. If we now take into consideration the means applied to effect this, we find that an apparatus with two vessels not working correctly together would be practically reduced to a Simple Effet. To obtain a greater evaporating capacity, powerful air pumps, condensers with cold water injection, condensed water pumps were used, also patent automatic condensed water receivers for drawing the water from the two vessels, which gave the desired results, but at the expense of the boiler house, by the great increase in the consumption of coal, so that the best possible type of boiler had to be used to reduce this. We shall see in the course of the following pages, that in the reconstruction of an evaporating plant for using the steam several times, many factories were able to use the boilers they had, and obtained a saving of coal simply by reducing the grate surface.

It is not necessary, on account of the small heating surface of the apparatus, to allow the juice from the filters, which is of 12·15° Beaumé to go to the vacuum pan,

* This dates from 1880, and is applied to Germany, Austria-Hungary, Russia, Belgium, and Holland, whilst France possessed Triple Effets many ears before.

this must first be evaporated in vacuum by direct Simple Effet, before it can be boiled to granulation.

But where is the progress in our evaporating plant in comparison with that which is represented in fig. 48, and described in paragraph 1,660 of the 8th chapter, Peclet, and proposed in the year 1849, 33 years ago.*

The present requirements of the sugar industry, point out to the sugar makers that the method of evaporation must be totally re-organised in order to obtain profitable results. Those who have succeeded in the wonderful system of diffusion, should succeed in producing a still more ingenious evaporating plant, the object of which should be to cheapen the production of high grade sugar juice which should leave the diffusion apparatus in a very watery condition. To this object my small abilities will be contributed, and I desire that the same may give impulse to having this burning question discussed and illustrated in all ways.

To attain this object, I shall enter on a criticism of the existing evaporating vessels and make proposals for removing their defects. This same should be done with the vacuum pans, and finally with the whole evaporation plant and all that belongs to it.

A.—THE EVAPORATION APPARATUS.

All the evaporating apparatus known up to the present may be divided into two principal systems, viz. :—

1. The system of evaporating apparatus with vertical vessels.

2. The system of evaporating apparatus with horizontal vessels.

SYSTEM I. We may further distinguish them, viz. :—

(*a*) Evaporation apparatus, which has vertical heating tubes, and through which the juice to be evaporated flows, and is heated externally by means of a steam chamber.

(*b*) Evaporation apparatus which have copper coils or serpentines, through which the heating steam flows, and the liquid to be evaporated is on the outside of the same, is found here and there as an auxiliary.

* These pages were first published in 1881, at this time we may say that considerable progress has been made.

SYSTEM II. is likewise divided into :

(*a*) Evaporation vessels with copper, brass, or iron tubes, which are different to the tube apparatus of system I, the steam being used internally, and surrounded by the juice.

(*b*) Such evaporating vessels having tubes instead of the long copper coils or serpentines, are heated as in system II.

Of all these constructions the last is seldom found amongst us, in Austria it has been most approved, as we shall see later on.

The reader will forgive me if I do not criticise each apparatus in the order in which I have set them down, but altogether and in the order in which it may be needed for our purpose. In the first place I shall examine the form of the apparatus in general, and each defect which is conditional in the same, and then review *the faults of the capacity of the heating surface as regards its capability of working in like comparison.*

If we consider a so called Robert's vertical evaporating apparatus, as it was constructed up to the year 1870, and is still sometimes constructed, we are struck above everything else with the very small space above the boiling juice, in proportion to the high column of juice and its small surface.

It is known to every one, that boiling liquids with a high column of juice and small surface, boil very wildly. *The reason is this : the boiling is a file of explosions of* steam bubbles which are developed under high pressure, whilst the quiet boiling of a small quantity on a large surface gives a comparatively low pressure, under which the steam bubbles are developed. The same comparison may be made with most of the horizontal apparatus, a liquid column of $1\frac{1}{2}$ metres high is not uncommon, but nearly the rule. A column of liquid which boils heavily and spurts, is *much more liable to cause a loss by boiling over, also of drops being drawn over by the vapour,* than liquids that boil quietly.

The loss will still be greater by boiling over, if the sides of the vessel are low. Both these defects are com-*mon in the construction of both systems.*

The vertical apparatus have at least the advantage that their sides are perpendicular, and that the velocity of the vapour rising to the dome remains the same, which allows the heavy drops of juice which rise with it to fall back into the boiling liquid.

The boiling over is easily prevented in the horizontal apparatus of the old construction. The velocity of the vapour coming from the juice is always greater as the diameter of the sides of the vessel are reduced at the surface of the liquid, and most especially under the surface of the boiling liquid, which causes the juice to spurt up to the dome, partly to be lost, in the better or worse constructed juice traps, if not caught it passes away with the condensed water from the tubes in the next vessel. Let us now consider the further loss which we suffer.

If we further examine the disadvantages of a high column of juice, we shall find that the mean capacity of performance of the heating surface is plainly insignificant, and the more so the higher the column. Now consider, we have as stated above, an evaporating apparatus (Robert's system) having vertical tubes with a juice column of 1½ metres, which is not unfrequent, and supposed to be only of the density of water, it will be equal to a pressure of 0·148 atmosphere on the bottom layer of the boiling liquid. If the vacuum gauge of the 1st vessel of a Double Effet shows a vacuum of 380 m/m. this will represent a pressure of 380 m/m. mercury or 0·5 atmosphere, the upper surface of the boiling liquid in this apparatus will boil at a temperature of about 82° C., whilst that at the bottom will boil at a pressure of $0·5+0·148=0·648$ atmos. or 88° C. As the heating surface in a Robert's apparatus is equally divided in a cylinder, the mean boiling temperature will be about 85° C.

Suppose we take another apparatus which has a a liquid column of 0·5 metres, then the liquid under a like proportion of vacuum will also boil at 82° *C* at the upper surface, whilst the lowest part which is under a pressure of $0·5+0·05=0·55$ atmos., will boil at 84° *C*, giving a mean boiling temperature of 83° *C*.

If we compare this result with the foregoing, we find a difference of 2° *C* against the apparatus with a high liquid column, so that the working capacity of the two apparatus with the same heating surface, will be in

direct proportion to the difference of temperature between the heating steam and the boiling liquid; therefore, it is evident that the apparatus with a juice column of $1\frac{1}{2}$ metres high, as compared with one having a column of 0·5 metres high is not so good as the latter, and the difference of temperature in the vessels of a Double Effet being generally 20° *C*, which is equal to 10%, so that the apparatus with $1\frac{1}{2}$ metres of juice column would require 10% more heating surface to do the same amount of work as an apparatus with a column 0·5 metres high. What loss arises from the juice left on the sides of the vessels after it has been drawn off in consequence of a low vapour space above the juice is known to every one, and we need not further dilate on it.

We now pass on to the examination of the heating surface, and take the horizontal apparatus with tubes through which the heating steam circulates.

A sugar factory which works about 2,000 metrical centals of beet-root in 24 hours, will require an engine of 120 horse power, and would give off about 30 kilos of exhaust steam per horse power per hour, representing a pressure of 0·5 atmos. and a volume of 1·12 cub. metres per second.

The heating chamber has 400 tubes each 0·055m. diam., to which the exhaust steam is supplied by a valve having a diameter of 0·250m., through which it will pass at a velocity of 23 metres per second, the condensed water being drawn off at the back of the apparatus.

The diameter of the above valve being 0·250 m/m. diam. = 0·049 sq. metres. 400 tubes each 0·055 m/m. diam. gives $400 \times 0{\cdot}00237 = 0{\cdot}948$ sq. metres, so that the steam or vapour will have a velocity through the tubes of only $49/948 \times 23$ metres per second = 1·18 metres initial speed. In other words it would be almost motionless, and the condensed water which it developed would be very incompletely carried off, so that the working capacity of the apparatus would be considerably retarded. In consequence of the bad heating capacity of the heating surface, caused by the fault mentioned, a great part of the heating steam or vapour passes off in the form of condensed water and is lost. To increase the velocity of the vapour through the tubes we must use powerful vacuum pumps and condensers to condense and draw off the vapour as it is formed.

That this is a direct loss of heat is, I think, not necessary to mention. It is also, I think, not necessary to go further into the explanation of the loss of heat which takes place, or the expansion of the heating steam in the heating chamber, as these are equally well known.

If we compare the construction of the present horizontal apparatus with heating tubes, with the so called Robert's apparatus, we will find that there is no great difference in their faults.

The vertical apparatus are much easier to keep clear of condensed water than the horizontal type, it being difficult to get rid of this water from the upper tubes of the latter, owing to the slow motion of the heating steam or vapour and its spreading unevenly in the tubes, causing the boiling to be very irregular and jerky which many mistake for good boiling, but it is nothing else than the strong working of the steam bubbles, which are developed under a high pressure in conjunction with the condensed water being periodically forced out of the tubes. The idea of circulating the juice in the tubes is a wrong one, and calls for a number of alterations, such as large circulating tubes, exterior circulation cylinder, serpentines and transverse plates in the interior heating space, etc., etc.

In the horizontal apparatus we must also adopt these remedies to improve the circulation of the heating steam. The tubes of the vertical apparatus are very easily cleaned, and that is all that it has in its favour over the horizontal apparatus of the old construction.

If we compare with both these evaporating apparatus, the horizontal apparatus of cylindrical form with copper coils, we come at once to better results. This type of evaporating apparatus was largely used in Russia.* As far as regards the height of the juice column and the limited extent of the boiling space they have the same faults as the apparatus we have mentioned. The arrangement of the heating system takes another form. The pipe which supplies the exhaust steam to the heating chamber is 0·250m. diameter, equal to an area of 0·049 sq. metr s, the pipe passes over into a rectangular transverse chest of nearly the same area, from this chest there are 19

* An Evaporating Apparatus in Russia, made by a Russian Engineer, serves us as an example.

copper coils projecting into the juice space each of 80 m/m. diameter, equal to an area of 0·005 sq. metre, and a total area of 0·095 sq. metres. The steam being introduced at an assumed speed of 23 metres per second will pass through the tubes with an initial velocity of 23×49/95=11·8 metres per second, and keep them clear of condensed water, which is not the case in the two foregoing systems, and gives this system of apparatus a higher working capacity than the others. They have, however, the injurious high liquid column, and the equally injurious small vapour space above the juice in common with the other systems which we have already described, also the loss of steam which arises from the non-condensing of the steam which passes through the coils, by being too short in proportion to their diameter. There are in such apparatus 15 coils, the total length of which is 756″ × 3″ in diameter, so that the length is 252 times the diameter, which is evidently incorrect, besides a large proportion of the steam must pass through uncondensed and be lost, as it discharges into an open waste water receiver.

Besides these 15 coils there are other four which have a length of 504″, which represent an unfavourable proportion. The surplus steam of this apparatus also goes into a water receiver, or to a vapour pump which is often provided with a water injection, and sometimes into the condenser of the air pump, this latter is most frequently the case.

Were these intermediate condensers, tube condensers, this otherwise absolutely lost steam could be used for other manufacturing purposes. The defects referred to are present in every category of the evaporating apparatus discussed up to the present, and must be set aside by the construction of some better apparatus.

By describing a new apparatus which has been erected under the name of the F. Wellner and H. Jelinek's, of which 300 are working in about 100 factories, I shall lay before my readers an evaporating apparatus where it is attempted to set aside all the defects mentioned. In the construction of it, we commenced on the principle that we must break with the old traditional form which is an unsuitable one, and construct an apparatus attaining to the object in view, and that the claim be just, which can be set up for such an apparatus, we are bound without reference as to whether the form be more or less pleasing.

If we examine this evaporating apparatus more closely, we shall find that it only requires a liquid column of 0·5 or 0·6 metre necessary to cover with juice the whole heating surface, which consists of tubes or coils, having at the most a diameter of 20 m/m. The coils are of such a length that the whole of the steam entering can be completely condensed. The total area of the tubes never exceeds the area of the steam supply pipes, so that the initial velocity of the steam entering the heatiug chamber remains always the same, consequently in our example, instead of 0·055m. and 1·18m., it is fully 23m. per second, a speed which is so great that the tubes always remain free from condensation water.

What an important part this plays is seen in the direct evaporation trial, which with the Wellner—Jelinek apparatus gave a transmission co-efficient of 24 W.E., heat units, per minute, per square metre, and difference of temperature, degree Cels., whilst the vertical apparatus only transmitted 16 W.E. heat units. Horizontal cylindrical apparatus of the old construction with tubes give still lower results.

To have the necessary length of tubes in the Wellner-Jelinck apparatus, these are arranged in serpentine form divided into several separate heating systems, or a direct coil is used of the necessary length, and of the diameter mentioned. The sides of the apparatus are vertical with a spherical top. The bottom is flat, and the liquid surface very large. The vapour outlets to the save-all have a very large area throughout, the boiling level of the liquid is kept to the height of the sides of the apparatus as 1 to 5, therefore boiling over is absolutely impossible as the boiling is very quiet. The circulation of the juice is exceedingly energetic, as the whole mass boils continously, which is not the case in apparatus with a high juice column.* There is also an arrangement, so that all the heating systems can be supplied either with exhaust or direct steam, or one with exhaust steam and

* What an influence the quick movement of the boiling liquid has may be seen from the following Table published in No. 18, 1881, of the "Jurnal des Fabricants de Sucre."

Speed of juice in metres per second.	Transmitted calories per square metre.
0·312	22·7
0·641	33·6
1·020	46·9
1·640	69·9

From this it may be seen that the same apparatus can be used on the threefold system if the speed of the juice supply be increased from 0·3 to 1·6 metres per second. This has naturally only reference to the size of the apparatus, [illegible]

the other at the same time with direct steam, without the *two steams mixing.* This apparatus was first constructed in 1878, and erected and worked in Bohemia in 1879.

To have a still greater effect from the heating steam, and to give a larger evaporating surface to the boiling liquid, the Wellner-Jelinek apparatus was also constructed as a stage apparatus and introduced into practice with advantage.

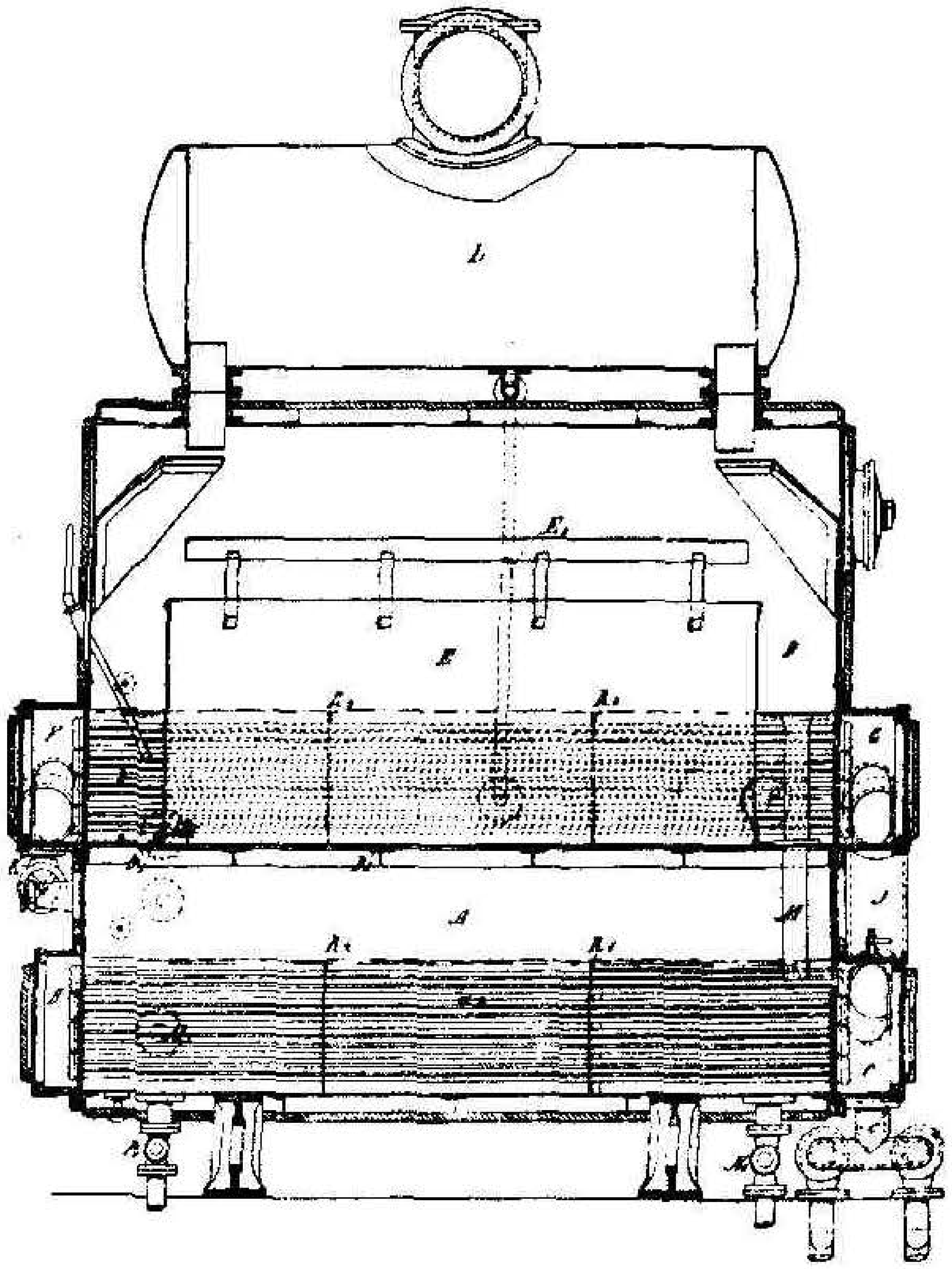


Fig. 1.

Fig. 1 is a vertical longitudinal section through the apparatus.

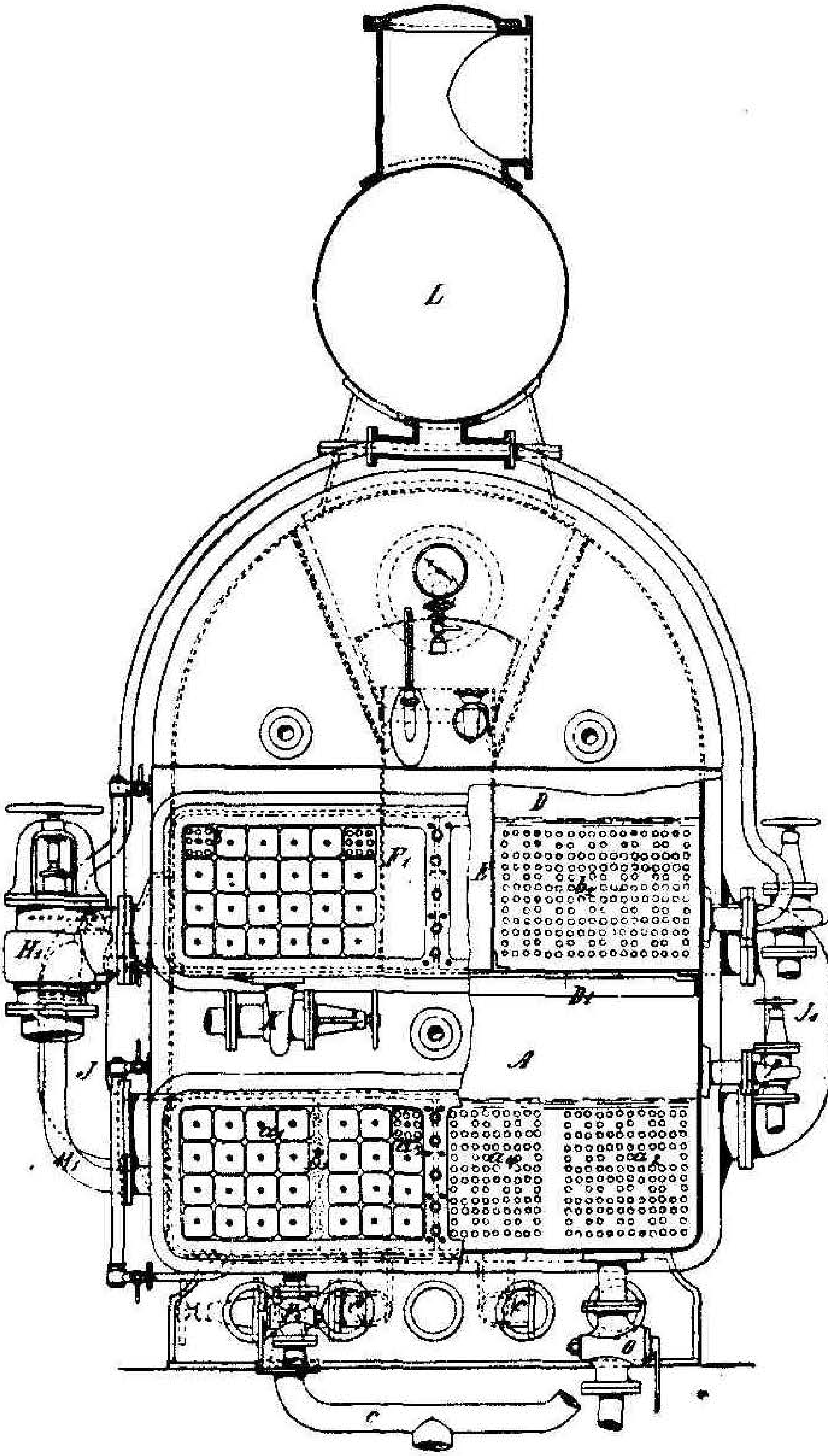


Fig. 2.

Fig. 2 is a front view of the apparatus with the cover of the heating chamber removed, and a partial section through the stages.

Fig. 3.

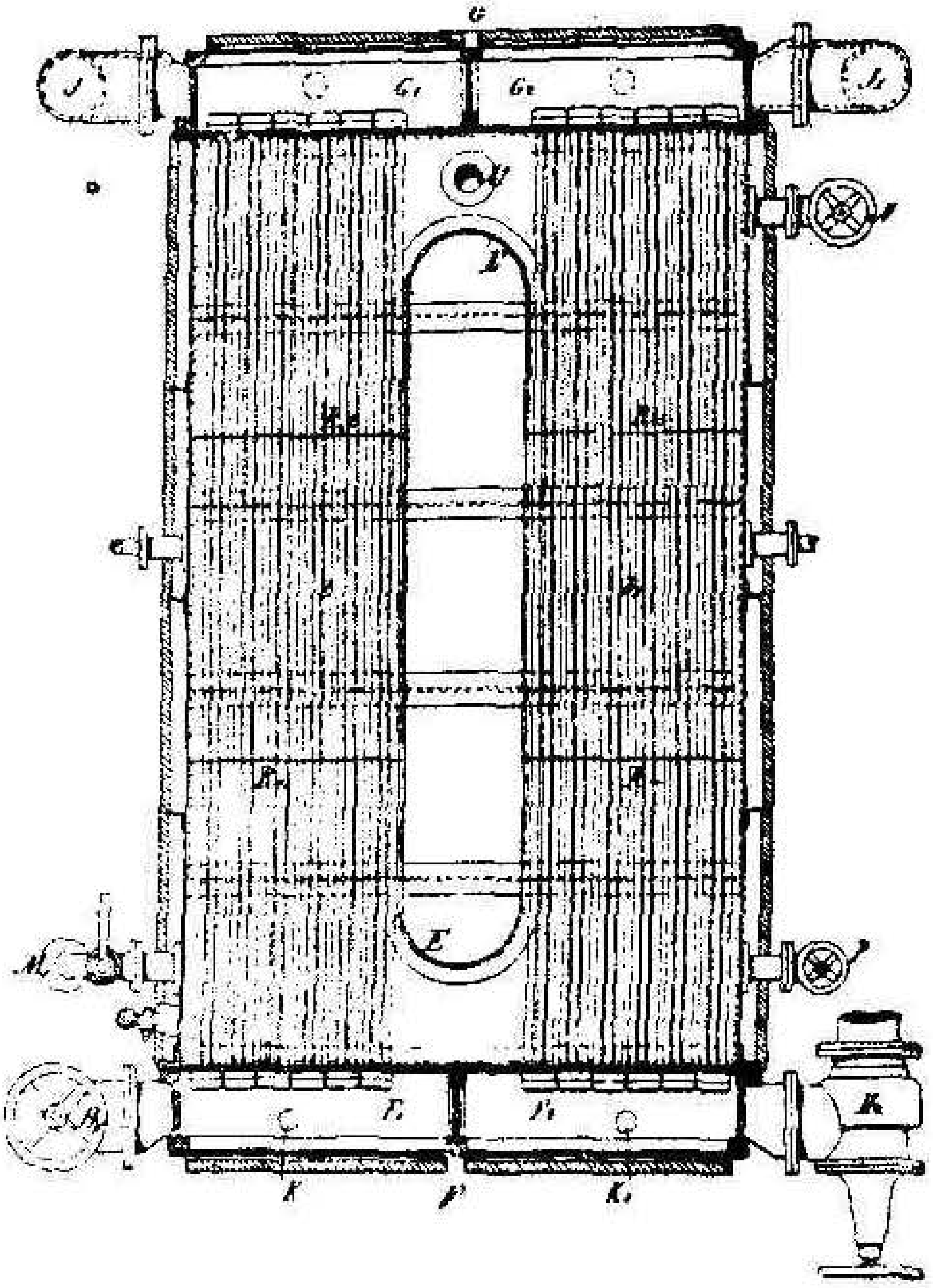


Fig. 3 is a horizontal section through the upper stage.

Fig. 4.

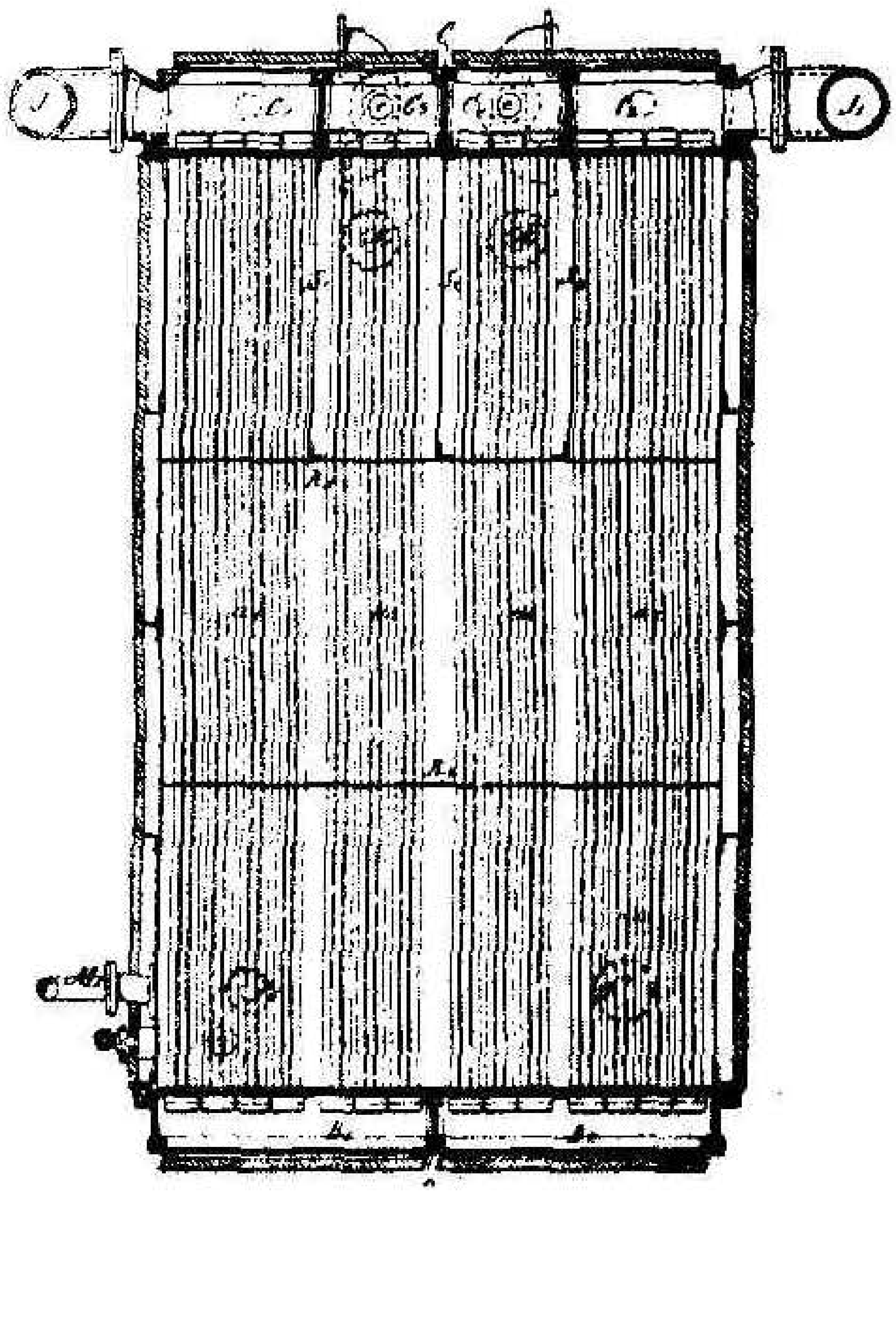


Fig. 4 is a horizontal section through the lower stage of the apparatus.

The lower part of the apparatus is the first stage A. The small tubes a^1, a^2, a^3, and a^4, open through the the front tube plate of the apparatus into the front steam chamber B and the back chamber C. The upper bottom of the stage D is higher than the bottom stage, and contains a smaller number of heating tubes b and b^1, by the vapour outlet E being placed in the middle of the bottom D, the lower stage A has less space. The heating tubes b of the upper chamber open into the heating chambers F and G, and are jointed to the front tube plate with india-rubber in the usual way, for the purpose of easily taking them out for cleaning.

The heating takes place as follows:—The heating chamber F of the upper stage D is divided into two parts f^1, f^2, by a partition, the exhaust steam being supplied by the valves H^1 and H^2. The steam flows through the heating tubes b and b^1 in two divided streams, from front to back, and enters the divisions G^1 and G^2 of the the steam chamber G, and then into the steam chamber C of the lower stage, through the connection pipes J and J^1 into the divisions C^1 and C^2, then through the heating tubes a^1 and a^2, from front to back, and passes over into the divisions B^1 and B^2 of the heating chamber B by the tubes a^3 and a^4, and finally to leave the apparatus as condensed water through the divisions C^3 and C^4 of the heating chamber C by the pipe and valve e. For heating the apparatus with direct steam, two steam valves K and K^1 are placed on the heating chamber f, so that the apparatus can be supplied half with direct and half with exhaust steam, or all direct or exhaust steam. By the rapid circulation of the steam the tubes are kept continuously at the same temperature, and there being a small quantity of juice over the tubes a very quick evaporation takes place, which would cause particles of juice to be lost with the vapour, were it not for the favourable form of the apparatus having a circular formed top, as well as an independent juice receiver L, which is of the usual construction, and prevents this inconvenience. The vapour of the lower stage A passes through the vapour outlet E into the upper stage D, joins there with that of the last named stage, and then enter together into the juice receiver L. By this the particles of juice which spurt over from the stage D, are prevented from falling into the lower stage by the vapour outlet E^1, which is covered over with a baffle plate, so that the juice can only

go from the upper into the lower stage through the supply pipe M or the discharge pipe M^1. The juice is supplied into the upper stage by the valve N and into the lower stage by the cock N^1, whilst the discharge of the juice from the lower stage is effected by the cock O. The valve P serves for the supply of steam into the interior of the apparatus, which with the cock P^1 at the bottom of the apparatus can be used for cleaning and blowing out the wash water. The rest of the fittings of the apparatus remain the same as used up to the present, and consist of the corresponding number of gauge glasses, vacuum gauge, thermometer, grease cock, glass stands, proof cocks, condensed water cocks, etc. The tubes are supported by plates to the height of the juice level, through which the tubes pass, and for this purpose the lower stage is provided with the plates R^1 and R^2, and the upper stage D with the plates R^3 and R^4.

B.—MULTIPLE EVAPORATING APPARATUS.

Independent of the peculiar nature of the evaporating vessels, the evaporating plant can, under similar circumstances, be designed both well and badly. What do we call a well designed evaporating plant? To that it may be replied: A well designed evaporating apparatus is that which will evaporate the largest quantity of juice with the least heating surface.

But on the other hand this can be very relative. For example, in an evaporating apparatus, by means of a rational re-using of the newly developed vapour in an evaporating system of multiple working, with one kilo steam, 2, 3, 4 or 5 kilos of water can be evaporated, and in spite of this we cannot affirm that this is a satisfactory solution; as it happens, we take what the first kilo of steam costs for producing the evaporation.

Each alteration in this respect bears consequences with it which must be considered and taken into account. Even all that falls to the evaporating plant stands in organic connection. Alterations in the boiler house, in the driving engine, etc., re-act on the evaporating plant, in like manner as alterations in the evaporating plant require further alterations in the machinery, and all these alterations are much influenced by local circumstances. In order to make the following generally intelligible, viz., the

description of an ideal evaporating plant, which can however be practically carried out, and to demonstrate that the arrangement which I shall propose is correct, I must treat in detail the theory of evaporation with single and multiple working, as well as of every mechanism in connection therewith, which I will do before I pass on to the practical application.

I will commence with the consideration of the evaporating apparatus by a Simple Effet, and close with a Quintuple Effet. I shall leave out of consideration the temperature at which concentrated sugar solution boils and assume boiling water, and fix the highest concentration point for unfiltered thick juice at the density of 50% Balling, as concentrated sugar juice filters with difficulty, and shall, in the course of this Essay, return to the further economical boiling of the same to masse cuite.

Thick juice, which has a weight of 50% Balling, boils under ordinary atmospheric pressure, according to Gerlach at a temperature of 102° C, and the finical calculator can easily bring the corrections to my reckoning according to the following table for boiling sugar solutions, if he pleases. According to Gerlach, sugar solutions boil at—

10 %	Balling	at	100·4°	C.
20 ,,	,,	,,	100·6°	,,
30 ,,	,,	,,	101·0°	,,
40 ,,	,,	,,	101·5°	,,
60 ,,	,,	,,	103·0°	,,
70 ,,	,,	,,	106·5°	,,
79 ,,	,,	,,	112·0°	,,
90·8 ,,	,,	,,	130·0°	,,

In an earlier annual of the Journal of the Sugar Industries of Bohemia, there is an essay by Professor Gustav Schmidt, which treats on the calculation for multiple effet evaporating apparatus, this same shall serve me as a guide. I shall use nearly the same notation of the single factors, but put them in a different order in the calculation as it suits our purpose.

I will take the normal pressure of the exhaust steam of the engines throughout at 0·5 atmospheres, and the corresponding temperature of the heating steam at 112° C. I further assume that the thin juice reaches the evaporating apparatus from the charcoal filters at a temperature of 75° C., that the highest normal vacuum be 608 m/m., and

that the corresponding temperature of this latter or of the thick juice is 60° C.

In consequence of this the difference of temperature between that of the heating steam and the evaporating liquid will be 52° C, which will be relatively divided into two, three, four and five parts, according as we shall have to do with a two, three, four or a five vessel apparatus.

I do not at first determine the heating surface of the apparatus to be used except for the 1st vessel, as the heating surface of the other bodies are fixed by calculation. Further, the vessels for multiple working shall have no other fixed point than that of the juice to be evaporated.

The notation of the single factor may be—

t'' = The temperature of the juice entering the apparatus.
t^1 = The temperature of the boiling juice.
t^2 = The temperature of the steam for heating this juice.
C = 22 the transmission co-efficient taken at 1 sq. metre heating surface per minute, and per 1° Celsius of the difference of temperature ($t^2 - t^1$), corresponding to the transmission co-efficient of the Wellner-Jelinek apparatus.
F = The heating surface of the evaporating apparatus.
Q = The amount per χ sq. metre and per minute of the heat unit = FC ($t^2 - t^1$).
λ^1 = That amount of heat which is necessary to transform 1 kilo of water at 0° Cels. under a pressure of constant steam at a temperature of t^1, expressed in calories = $606 \cdot 5 + 0 \cdot 305\ t^1$.
r^2 = *The latent heat which is given off by condensation* in the heating space = $607 - 0 \cdot 708\ t^1$.
Dg = The weight of steam which is condensed in the tubes expressed in kilogrammes.
Wg = The weight of water in kilogrammes evaporated by the heating surface of the evaporating apparatus.

It follows—

Ex. 1— as: $Q = Dg\ r^2 \ldots\ldots\ldots Dg = \frac{Q}{r^2}$

„ 2—further, $Q = Wg\ (\lambda^1 - t'') \ldots Wg = \frac{Q}{\lambda^1 - t''}$

I also leave out of the calculation the loss through the cooling of the heating space, as we assume a sufficient amount of exhaust steam, which compensates for the loss by a continual back pressure. The loss through conden-

sation on the sides of the apparatus is nil in consequence of a good covering. Any one is free to add, at pleasure, the various losses at the end of the calculation as corrections.

I.—SIMPLE EFFET.

$t^0 = 75°$ Cels.
$t^1 = 60°$ „
$t^2 = 112°$ „
$t^2 - t^1 = 52°$ „
F = 100 sq. metres.
C = 22 W. E. = heat units.
Q = 100 × 22 × 52 = 114430 W. E. = heat units.

$$Dg = \frac{114400}{607 - 0 \cdot 708 \times 112} = 216 \cdot 3 \text{ kilos of steam.}$$

$$Wg = \frac{114400}{606 \cdot 5 + 0 \cdot 305 \times 60} = 208 \text{ kilos of water.}$$

Therefore, a simple effet will evaporate 208 kilos of water per 100 sq. metres per minute or 124 per sq. metre per hour, if it enters the apparatus at 75° C.

To evaporate 208 kilos of water there is required 216·3 kilos of steam, therefore, 1 kilo of steam evaporates 0·96 kilos of water.

II.—DOUBLE EFFET.

I.—Vessel : $t^2 - t^1 = \frac{52}{2} = 26°$ Cels.
$t^2 = 112°$ Cels.
$t^1 = 86°$ „
$t^0 = 75°$ „
F = 100 sq. metres.
C = 22 W. E. = heat units.
Q = 22 × 100 × 26 = 57200 W. E. = heat units.
$\lambda^1 - t^0 = (606 \cdot 5 + 0 \cdot 305 \times 86) - 75 = 557 \cdot 73$ W.E = heat units.

$$Dg = \frac{57200}{527 \cdot 7} = 108 \cdot 3 \text{ kilos of steam condensed}$$

$$Wg^1 = \frac{57200}{557 \cdot 73} = 102 \cdot 5 \text{ kilos of water evaporated.}$$

II.—Vessel $t^2 - t^1 = \frac{52}{2} = 26°$ Cels.
$t^2 = 86°$ Cels.
$t^1 = 60°$ „
$t^0 = 86°$ „

$r^2 \quad = 607 - 0{\cdot}703 \times 86 = 546$ W—E = heat units.

$\lambda' - t'' = (606{\cdot}5 + 0{\cdot}305 \times 60) - 86 = 638{\cdot}8$ W. E. = heat units.

$Q \quad = Dg^2\ r^2\ da\ (Dg^2 = Wg^1) = 102{\cdot}5 \times 546 = 55965.$

$F \quad = \frac{55965}{22 \times 26} = 97{\cdot}84$ sq. metres.

$Dg^2 \quad = 102{\cdot}5$ kilos of steam condensed.

$Wg^2 \quad = \frac{55965}{538{\cdot}8} = 103{\cdot}8$ kilos of steam evaporated.

We have therefore evaporated in the two vessels per minute, as follows: 197·84 sq. metres heating surface =102·5+103·8=206·3 kilos of water or per sq. metre per hour 62·5 kilos, and 108·3 kilos of heating steam have been condensed.

According to this 1 kilo of steam evaporated 1·9 kilo of water. From the calculation itself, it follows that the 2nd vessel apparently requires theoretically a small heating surface, as it has less heating steam to condense than the 1st vessel; whilst in the 1st vessel there are 108·3 kilos of steam condensed, the 2nd has only 102·5 kilos to condense. Further, the working capacity of the 2nd vessel appears greater per square metre of heating surface and per kilo of heating steam than the 1st vessel; then in the 1st vessel 100 sq. metres of heating surface evaporates 102·5 kilos of water and condenses 108·3 kilos of steam, whilst in the second vessel 97·84 sq. metres of heating surface evaporates 103·8 kilos water and condenses 102·5 kilos of steam per minute.

This difference is accounted for by the juice supplied from the 1st vessel to the 2nd having a higher temperature than the boiling juice in the 2nd vessel and serves partly for evaporating it under the lower pressure which is in the 2nd vessel, and is to the advantage of the heating surface and heating steam of the 2nd vessel.

It may, however, be generally said, that both vessels will have the same difference of temperature for the same heating surface, and that 1 sq. metre in a Double Effet has half the evaporating capacity of a Simple Effet. Therefore, to have the same capacity it must be twice as large,

whilst the heating steam on the contrary evaporates double the quantity of water.

The calculations for a Triple, Quadruple, etc., Effet are the same as for as Simple and Double Effet.

I shall not carry these calculations further, so as not to weary the reader, but give a table on the following page, which shows the result of these calculations.* (See page 128.)

From this Table it is seen that, in round numbers, 1 kilo of steam will evaporate 1, 2, 3, 4 or 5 kilos of water, according to whether it passes for conversion into a one, two, three, four or five vessel apparatus. Whilst the heating surface will be greater in proportion.

We see further that the heating surface in all the vessels should be nearly the same, as there is no data for making the difference of temperature greater or less in the separate vessels.

We find that the last vessels of a Multiple Effet work more economically than the first. This, however, is only apparent, the greater evaporation in the last vessel is caused by the boiling point in the same being lower than that in the first, and the temperature of the supply juice higher than that of the boiling juice.

We further find that the heating surface from the second to the fifth vessel is increased. This finds its explanation in the following :—

$$F = \frac{Q}{(t^2 - t^1)\ 22} = \frac{Wg\ (\lambda^1 - t^0)}{(t^2 - t^1)\ 22}$$

Thus, $(t^2 - t^1)\ 22$ is a constant, whilst Wg changes as may be seen in the Table, and for example is always

$$Wg^2 < Wg^3 < Wg^4 < Wg^5 \text{ etc.}$$

Thus the value of $(\lambda^1 - t^0)$ is always greater in the following vessel. Accordingly Q in like manner is always greater, and with it also F. These changes are, however, so unimportant, that in a Quintiple Effet the heating surface of the first vessel may be repeated five times.

I cannot forbear, on this occasion, from expressing myself, against the extreme increase of the heating surface of the

* The values contained in this Table concerning point 7, are to be multiplied by a co-efficient of 0·75 for a Wellner-Jelinek apparatus, and of 0·50 for a Robert's apparatus To have a serviceable data for practice, the incrustation of the tubes, which causes irregular working must be taken into consideration.

	Simple Effet.	Double Effet.		Triple Effet.			Quadruple Effet.				Quintuple Effet.				
		I.	II.	I.	II.	III.	I.	II.	III.	IV.	I.	II.	III.	IV.	V.
1.—$t_2 - t_1$ difference of temperature fixed $\frac{52}{n^1}$	52	26	26	17·3	17·3	17·3	13	13	13	13	10·4	10·4	10·4	10·4	10·4
2.—t_2 *Temperature of heating* steam	112	112	86	112	94·6	77·4	112	99	86	73	112	101·6	91·2	80·8	70·4
3.—t^1 do. of boiling juice	60	86	60	94·6	77·4	60	99	86	73	60	101·6	91·2	80·8	70·4	60
4.—Vacuum in millimetres ...	608	304	608	112	442	608	27	300	434	608	−[2]	207	393	521	608
5.—Absolute pressure in millimetres	152	456	152	648	318	152	733	480	266	152	804[3]	553	367	239	152
6.—Quantity of steam condensed	129·7	64·98	61·50	43·35	40·81	41·16	32·52	30·54	30·73	30·92	26·01	24·40	24·51	24·60	24·73
7.— " " water evaporated	124·8	61·50	62·28	40·81	41·16	41·52	30·54	30·73	30·92	31·11	24·40	24·51	24·60	24·73	24·74
8.—Transmission co-efficient for *Wellner-Jelinek apparatus* .	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
9.—Heating surface calculated theoretically, when the 1st vessel is 100[4].	100	100	97·84	100	96·2	99	100	95·5	98·0	100	100	95·1	96·8	98·7	100·3
10.—1 kilo of steam supplied to the vessel will evaporate in kilos	0·9	1·96		2·85			3·79				4·72				
11.—To evaporate 100 kilos of water from the juice required steam in kilos	111·11	51·03		35·08			26·38				21·18				
	I	I.	II.	I.	II.	III.	I.	II.	III.	IV.	I.	II.	III.	IV.	V.

[1] Number of vessels

[2] Is pressure

[3] 44 m. m. actual press.

[4] The juice is supplied at a heat of 75° C.

apparatus which is connected with a Multiple Effet. This is no great error theoretically, as it neither assists nor diminishes sensibly the working capacity of the apparatus, it being assumed that the heating surface of the apparatus is clean.

If the heating surfaces of the last vessels be taken as greater, then the difference of temperature of the first vessels will also be greater, in inverse proportion to the heating surface, it being taken for granted that the last vessel is in a condition to condense the quantity of vapour arising from the previous vessels. The first vessel has to evaporate more water in proportion per square metre per hour, than it should do. Hence the last vessel evaporates relatively less, so that the evaporation per square metre and per hour remains nearly the same. The heating surface of the last vessel being coated with an incrustation of lime deposited from the juice, the evaporating capacity is diminished, and to overcome this it has been proposed to increase the heating surface which, in my opinion is wrong.

To make this clear I will give a special case. For instance, a sugar factory has to evaporate 300,000 kilos of water in 24 hours, either by a Double or Triple Effet with vertical tubes, Robert's system, he giving the size of the apparatus and the division of the heating surface. And taking the evaporation at 20 to 30 kilos of water per sq. metre per hour, it follows that, if it works 22 working hours the Triple Effet should have $\frac{300,000}{22 \times 20} = 681 \cdot 8$ square metres, and a Double Effet 454·5 square metres. In both cases this is generally taken in round numbers to the detriment of the heating surface, for example 680 square metres, or 450 square metres. The division and arrangement would probably be as follows :—

In the Double Effet—

II. vessel at 150, II. vessel 150, I. vessel 150.
a b

The centre vessel boils the same as the others or probably under more favourable auspices.

I. vessel 180, II. vessel 270.

The Triple Effet would probably have the following divisions :—

I. vessel 180, II. vessel 225, III. vessel 275.

Any desired division can be made, and these decided on are only to be taken as happening by chance, which up to the present is generally the case.

A possible increase of the temperature of the heating steam in the first vessel, and a larger supply of exhaust steam must not be thought of as this can only take place to a certain limit.

What will be the result? In any case the apparatus at the commencement will work well, and evaporate from 20 to 30 kilos of water, but the more tubes in the last vessel become incrusted, so much the less will the apparatus evaporate, and at last it must be cleaned to effect its original capacity. The same would also be the case if the heating surfaces were made in the proportion of 1 : 1 or 1 : 1 : 1, in the same time and same proportion, as a simple calculation on the above basis gives. The apparatus will work differently if instead of 680 square metres of heating surface, 450 is taken, then the division should be as follows:—

Double Effet - -	I. vessel 225,	II vessel 225
Extra heating surface for incrustation - - - -		100
	I. vessel 225,	II. vessel 325

This 100 can be any number we choose, and in the same proportion for the Triple Effet roundly 690 square metres of heating surface.

	I. vessel 230	II. vessel 230	III. vessel 230
Extra for incrustation		50	100
Amount -	*230*	*280*	*330*

In both cases there is actually a gain of heating surface, which I need not demonstrate, since I have actually given extra surface. As soon, however, as the incrustation becomes greater the Q of the extra surface diminishes and at last vanishes, and the Q of the extra required heating surface becomes less; work must be stopped to clean the apparatus. Would it not be better to put this extra surface in a separate vessel, and place it alongside the working apparatus, so that it could be immediately set to work when the incrustation of the tubes begins to impede the work? Why have we an extra boiler? There is no ground on which the want of this could be excused, not even the question of cost.

After this digression we will return again to the real question, and on the basis of the above calculations and formulæ, enter on an enquiry as to which of the above ideas will shew us how to fully make use of our evaporating apparatus, and bring the evaporating plant into a rational union with the other parts of the sugar factory.

The table on page 128 is calculated on the basis that $t^2 - t^1$ is $= \frac{52}{n}$; n denotes the number of evaporating vessels which work together. 608 m/m is assumed as the nominal height of the vacuum, and the pressure of the exhaust steam is half an atmosphere; therefore $t^2 =$ 112° C.

The corresponding heating surface would be decided by calculation.

The temperature of the thin juice supplied, and which passes from vessel to vessel interferes with the result for calculating the heating surface, as this heat is partly used for forming steam successively without taking the heating surface of the apparatus into consideration.

From this cause also arises the variation of the heating surface in the other vessels, which, nevertheless, should be the same, as the differences of temperature are the same. The calculated surfaces are those corresponding to the regular working of the whole evaporation apparatus, and the juice supplied has a temperature of 75° C, when this temperature changes, the working capacity of the heating surface changes in proportion.

I may here again once more mention that all the calculations are based on boiling water; if we take boiling juice, the quantity evaporated will be as the difference of temperature becomes less, the temperature of the heating steam remaining the same, because the boiling point of the concentrated sugar solution is higher than that of water, the concentration of the juice increases gradually in the vessels following each other, and also the difference of temperature in inverse proportion. If we take these into calculation, with the assistance of ne Table on page 128, on the boiling point of concentrated sugar solution, we should find that the whole difference in temperature will scarcely be 4% less, and this number is also in this case the rectification co-efficient which is to be

applied to the whole heating surface, and in the proportion as the concentration increases in the following vessels, the *heating surface* must be greater by this small amount, as giving in the table referred to, and we come to the result that the heating surface of the separate vessels should be to each other, as 1 : 1 : 1, which is nearly correct and can be recommended *in practice.**

By supplying *thin juice at 75° Cels., it not only gives* the proportional quantity of heating surface, but on this temperature depends how many kilos of water, one kilo of steam converted into vapour will evaporate. The higher the temperature of the juice supplied the more water 1 *kilo of steam* will evaporate from it. This increased effect of the steam or vapour is only an apparent one, as each calorie which is required to increase the evaporation is not obtained from the steam, but from the juice supply, and has an extraneous origin; therefore, the calorie of the juice in a multiple evaporation apparatus is equally used multiple. The higher the temperature of the juice supplied so much the more economically does the apparatus work. I will here state a practical example.

Take for instance, if the thin juice before it is supplied *to the first vessel, is forced at a sufficient velocity and* under a pressure of 1 atmosphere by means of a pump through a coil, it will be heated to 120° C. before it enters the apparatus. With a Double Effet we obtain the *following results*:—

I. Vessel: $t^2 - t^1 = \frac{52}{2} = 26°$ Cels.

$t^2 = 112°$ Cels., $t^1 = 86°$ Cels., $t'' = 120°$ Cels.†

$C = 22$, $F = 100$ sq. metres.

$Q = 22 \times 100 \times 26 = 5700$ W.E. heat units.

$r^2 = (607 - 0{\cdot}708 \times 112) = 527{\cdot}7$

$\lambda^1 - t'' = (606{\cdot}5 + 0{\cdot}305 \times 86) - 120 = 512{\cdot}73.$

$Dg^1 = \frac{57200}{527{\cdot}7} = 108{\cdot}3$ kilos of condensed steam or vapour.

$Wg^1 = \frac{57200}{512{\cdot}73} = 111{\cdot}1$ kilos of water evaporated

* An extra vessel as explained on a previous page can only be advantageous.

† In future I leave out the notation "Cels." with the remark, that all the notations of the temperature are to be understood as Celsius.

II. Vessel: $t^2 - t^1 = \frac{52}{2} = 26°$

$$t^2 = 86°,\ t^1 = 60°,\ t^0 = 86°$$

$$C = 22;\ F \text{ unknown.}$$

$$\lambda' - t^0 = (606{\cdot}5 + 0{\cdot}305 \times 60) - 86 = 538{\cdot}8$$

$$r_2 = (637 - 0{\cdot}708 \times 86) = 546$$

$$Wg_1 = Dg_2 \text{ is } Q = Dg^2\ r_2 = 111{\cdot}1 \times 546 = 60660 \text{ whence}$$

$$F = \frac{60660}{22 \times 26} = 106 \text{ sq. metres.}$$

$$Wg_2 = \frac{60660}{538{\cdot}8} = 112{\cdot}76 \text{ kilos of water evaporated.}$$

According to this 108·3 kilos of steam or vapour = 111·1 + 112·76 = 223·86 kilos of water evaporated, *or with 1 kilo of steam or vapour 206 kilos of water;* and under similar circumstances with juice at 75°, only 1·96 kilos of water would be evaporated.

This calculation for a Triple Effet gives 1 kilo of steam or vapour would evaporate 3·09 of water instead of 2·85 kilos as above.

In practice the object is to obtain the greatest quantity of work from a given heating surface, on which basis I give the following two calculations to serve the reader as a guide, if he goes over these calculations it may also give him an idea of how inexpedient it is to give extreme dissimilar heating surfaces to the evaporating vessels.

1. Example : Double Effet. The surfaces of both vessels are dissimilar. To find the difference of temperature which will give the maximum working capacity for both vessels

1. Vessel : $t'_2 = 112°$	2. Vessel : $t''_2 = t''_1 = x°$
$t'_1 = x°$	$t''_1 = 60°$
$t_0 = 75°$	$t''_0 = t_1 = x$
$F_1 = 100$ sq. metres	$F_2 = 150$ sq. m.
$C = 22$	$C = 22$

$$Q_1 = Q_2$$

We have first of all to decide the mean temperature :—

$$Q_1 = F_1\ C(t'_2 - x)$$

$$Q_2 = F_2\ C\ (x - t''_1)$$

Therefore : $F_1\ C\ (t'_2 - x) = F_2\ C\ (x - t''_1)$ and

$$F_1\ (t'_2 - x) = F_2\ (x - t''_1)$$

Whence $\quad x = \dfrac{F_1\ t'_2 + F_2\ t''_1}{F^1 + F_2}$

The value substituted gives $x = \frac{100 \times 112 \times 150 \times 60}{100 + 150} = 80{\cdot}8^\circ$

There is therefore, if we always take $t^n_2 - t^n_1 = d^n$:
$d^1 = 112 - 80{\cdot}8 = 31{\cdot}2$ the difference of temp. for 1 vessel,
and $d^2 = 80{\cdot}8 - 60 = 20{\cdot}8^\circ$,, ,, 2 ,,

There is further $Q^1 = F^1\,Cd^1 = 100 \times 22 \times 31{\cdot}2 = 68640$ W.E heat units.

and $Q^2 = F^2\,Cd^2 = 150 \times 22 \times 20{\cdot}8 = 68640$ W.E. heat units

From this is calculated :—

$$Dg_1 = \frac{Q_1}{r_2} = \frac{68640}{607 - 0{\cdot}708 \times 112} = 130 \text{ kilos of steam.}$$

$$Wg_1 = \frac{Q_1}{\lambda_1 - t_0} = \frac{68640}{606{\cdot}5 + 0{\cdot}305 \times 80{\cdot}8) - 75} = 123{\cdot}7 \text{ ,, ,, water.}$$

$$Dg_2 = Wg_1 \quad - \quad - \quad - = 123{\cdot}7 \text{ ,, ,, steam.}$$

$$Wg_2 = \frac{Q_2}{\lambda_1 - t_0} = \frac{68640}{(606{\cdot}5 + 0{\cdot}305 \times 60) - 80{\cdot}8} = 126{\cdot}1 \text{ ,, ,, water.}$$

Further there is $\frac{60\ Wg_1}{100} = 74{\cdot}22$ kilos of water evaporated per sq. metre, and per hour in 1 vessel.

And $\frac{60\ Wg_2}{150} = 50{\cdot}44$ kilos of water evaporated per sq. metre and per hour in 2 vessels.

Therefore, on an average the Double Effet, where it is $F_1 : F_2 = 100 : 150$ only evaporates 59·95 kilos of water per sq. metre and per hour, instead of 61·89 kilos, which it would evaporate with equal surfaces.

2. Example : Triple Effet. The surfaces of the 3 vessels are dissimilar. To find the difference of temperature which gives a maximum working capacity to all 3 vessels.

1. Vessel.	2. Vessel.	3. Vessel.
$t'_2 = 112^\circ$	$t''_2 = x$	$t''' = y$
$t'_1 = x$	$t''_1 = y$	$t'''_1 = 60^\circ$
$t_0 = 75^\circ$	$t_0 = x$	$t_0 = y$
$F' = 100$	$F_2 = 150$	$F_3 = 200$
$C = 22$	$C = 22$	$C = 22$

$$Q_1 = Q_2 = Q_3.$$

Therefore, $F_1\,(t'_2 - x) = F_2\,(x - y) = F_3\,(y - t'''_1)$

We determine from the equation 1 and 3 that x is thus—

$$x = \frac{F_1\,t'_2 - F_3 y + F_3\,t_3'''_1}{F_1}$$

If we substitute for this expression the equation 2 and 3 and determine y, then we have :—

$$y = \frac{F_1 F_2 t'_2 + F_2 F_3 t'''_1 + F_1 F_3 t'''_1}{F_1 F_2 + F_2 F_3 + F^1 F^3}$$

The known value substituted gives :

$$y = \frac{100 \cdot 150 \cdot 112 + 150 \cdot 200 \cdot 60 + 100 \cdot 200 \cdot 60}{100 \cdot 150 + 150 \cdot 200 + 100 \cdot 200} = 72^\circ \text{ C.}$$

The result of this is $d_3 = 72 - 60 = 12^\circ$ the difference of temperature of the 3 vessels.

If we take $F_3 \; d_3 = P_1$, then $F_2 \; d_2 = F_1 \; d_1 = P$; because $Q_1 = Q_2 = Q_3$, therefore,

$$d_1 = \frac{P}{F_1}; \; d_2 = \frac{P}{F_2}; \; d_3 = \frac{P}{F_3}$$

For the 3rd vessel P is known $= 12 \times 200 = 2400$

It follows that $d_2 = \frac{2400}{150} = 16^\circ$ temperature of 2nd vessel.

And $d_1 = \frac{2400}{100} = 24^\circ$ „ of 1st „

And also $112^\circ - 24 = 88^\circ$ boiling temperature of 1st vessel.
$88^\circ - 16 = 72^\circ$ „ „ „ 2nd „
$72^\circ - 12 = 60^\circ$ „ „ „ 3rd „

$$D g_1 = \frac{100 \times 22 \times 24}{607 - 0 \cdot 708 \times 112} = \frac{52800}{527 \cdot 71} = 100 \text{ kilos of steam.}$$

$$W g_1 = \frac{52800}{(606 \cdot 5 + 0 \cdot 305 \times 88) - 75} = 94 \cdot 56 \text{ „ „ water.}$$

$$D g_2 = W g_1 \quad - \; - \; - \; - = 94 \cdot 56 \text{ „ „ steam.}$$

$$W g_2 = \frac{52800}{(606 \cdot 5 + 0 \cdot 305 \times 72) - 88} = 97 \cdot 60 \text{ „ „ water.}$$

$$D g_3 = W g_2 \quad - \; - \; - \; - = 97 \cdot 69 \text{ „ „ steam.}$$

$$W g_3 = \frac{52800}{(606 \cdot 5 + 0 \cdot 305 \times 60) - 72} = 905 \cdot 00 \text{ „ „ water.}$$

Or there is evaporated per square metre and per hour in

1st Vessel $\frac{97 \cdot 56 \times 60}{100} = 56 \cdot 73$ kilos of water.

2nd „ $\frac{97 \cdot 50 \times 60}{150} = 39 \cdot 14$ „ „

3rd „ $\frac{95 \cdot 50 \times 60}{200} = 28 \cdot 65$ „ „

The average being 38·36 kilos of water.

So that the consumption of steam remains the same in a Double Effet as in a Triple Effet, as per Table page 128.

If we compare this water evaporation per sq. metre of heating surface with that of table on page 128, we see that the working capacity per sq. metre of heating surface has fallen, whilst a Double Effet, with equal difference of temperature, and calculated heating surface, evaporates on an average 62 kilos of water per sq. metre of heating surface per hour, and the Double Effet in which F^1, F^2 = 100; 150 only evaporates 59 kilos per sq. metre per hour, which is about 5% less. With a Triple Effet the proportion will not be so good. A Triple Effet of the best construction evaporates about 41 kilos of water per sq. metre per hour, and if calculated as above evaporates only 38·36 or about 6½% less, and with a Quadruple and Quintiple Effet this difference is still greater.

For practical use these small differences are of no great importance. The stating of the same, however, always has its value, as they prove that dividing the total heating surface into unequal parts in the manner described is not only incorrect, but prejudicial, as the greater the difference in the heating surface of the separate vessels, so will the working capacity be less. The calculations for a Quadruple and Quintiple Effet are carried out exactly in the same manner.

If we now take the formula $Q = FCd$, we see that if Q denotes the working capacity of the apparatus, this Q will be greater if only one single factor be increased, and on the other hand will be smaller if the separate factors be reduced. It is natural that if F be made larger, the working capacity of the apparatus must be greater. But it is also equally correct that if C or d be increased the same takes place. F can only be increased by adding extra surface, but, on the contrary with C, it can be increased without this being done, by increasing the transmission capacity, and keeping the tubes clear of condensation water. This is the only possible way to increase C, and which can be obtained by keeping a strong supply of steam. Keeping the heating surfaces clean, will also prevent C from being reduced.

Respecting the difference of temperature d, it is completely in our hands to increase the working capacity

of an apparatus in this direction, assuming that we have already set out the maximum limit. How this can take place we shall now explain.

The increasing of *d* is possible in two directions, that is to say :—

1. By lowering the boiling point of the liquid.

2. By increasing the temperature of the heating steam.

As regards lowering the boiling point, we are confined to a narrow limit, as it depends upon the reduction of the atmospheric pressure, which burdens the boiling liquid.

If in the last vessel of an evaporating apparatus we could form and maintain a vacuum of only 0·1 atmosphere, the liquid would boil at about 46° C, instead of 60° C ; we should thereby gain a difference of temperature of 14° C, with a total heat of 52°, which we take in our calculation, would increase the working capacity of the apparatus by 27% ; but as this is not possible, and an average vacuum of 608 m/m is considered good, we must as far as possible hold to the second point. The reason why we cannot obtain a high vacuum, or as good as that attained by a condensing engine, is that the boiling juice contains organic bodies, gases, and air which mix with the vapour, and are condensed with difficulty. That atmospheric air mixes with the steam to be condensed, I think I need not dilate on.

We will now take point 2, and endeavour to increase the difference of temperature by giving a higher temperature to the heating steam. This we can effect in different ways.

For evaporating juice, the exhaust steam from the engine is used, and when this is not sufficient, direct steam must be added, so that we have to take two sources of steam into consideration.

If exhaust steam is used, its temperature can only be increased by superheating it by means of a suitable source of heat, or when it is exhausted under greater pressure. The first does not generally conduce to the purpose, as the source of heat generally fails; the latter is risky. Increasing the pressure of the exhaust steam at the back of piston, means increase of pressure to drive it, in other words, the direct steam is not given

direct to the apparatus, but is introduced through the steam cylinder of the engine. If a pressure of 1½ atmospheres is given to the exhaust steam, it is done so as not to make the heating surface too large, and to prevent the loss of capital which has been saved by not using direct steam. It will be seen later on that ½ atmosphere of back pressure is quite sufficient for the engine, and that the arrangement of the evaporation plant must be made to correspond.

The difference of temperature can be completely controlled by raising the temperature of the heating steam, that is, by using direct steam separately, as with its pressure the temperature increases, at the same time the difference of temperature depends on other conditions, which I shall now more particularly describe.

If a liquid which is not boiling is heated, it will be found that *the transmission capacity of the heating surface falls* extraordinarily, and under certain circumstances as much as 60% to 80%, so that if 1 square metre of heating surface has a transmission co-efficient of 25, this co-efficient will become very small. This is not the fault of the heating surface, as it remains the same; it is the deficiency of the difference of temperature. The liquid to be heated or evaporated, must be considered as being divided into concentric layers, which cover the heating tubes that in the immediate vicinity of the tubes will have the highest temperature; if the juice is motionless, it causes the direct difference of temperature to be less than if these layers be renewed by means of any mechanical appliance, allowing the colder parts of the liquid to come in contact with the heating surface. This last is proved in boiling, by the strong movement of the liquid; the more lively the boiling the more heat is transmitted, since *the difference of temperature continues to be maintained.*

The difference of temperature will also become less, if the temperature of the heating steam falls, that is to say, its pressure is reduced, which will be the case if the pressure in the tube is not maintained by a counter pressure. If the ends of the tubes are open, which is generally the rule in the first vessel, there will be no pressure, in consequence of which the heat of the steam becomes less; the difference of temperature is an illusory one, all these phenomena shall be once more specially discussed.

C.—THE VACUUM PAN.

The Vacuum Pan is an evaporating apparatus, and is under the same laws as I have named for the Multiple apparatus. If calculations have to be made of its working capacity and the economic value of the heating steam, it is quite accurate to make them with the same formula as those used for the Multiple apparatus.

The vacuum pan is quite as old, even older, than the Multiple apparatus, but in spite of the giant progress of the sugar industry, it has advanced the least. The vacuum pan, the most precious thing of the old sugar master, is in its beaming splendor, like a pampered child, which has remained with all the faults of such a child, placed as far as possible in the best and most conspicuous part of a sugar factory; bright and polished it stands, like a globe to exercise its attractive power on the youth of the sugar industry, who, with inexpressible longing, look for the day when they are to be initiated into the mysteries of the proof-stick. The vacuum pan of the year 1882 differs very little from that by which the grandfathers of our present sugar boilers held the proof-stick in their hands, it having the same unpractical globular form, low and confined evaporating space, small heating surface only calculated for compressed steam, small space for the charge, and closely laid serpentines, which make an easy discharge for hard boiled sugar of a course grain almost impossible, and in which 1 kilo of boiling mass is of more value than nearly 10 kilos of boiling juice in one vessel of a Multiple apparatus, has generally ten times less evaporating space than the latter, and a juice receiver of the same smallness, generally called a save-all.

The reason that this is so, and not otherwise, is that up to the time when these pages were written, the sugar factories here were erected for a small daily capacity, and hence required small vacuum pans.

The present position of the sugar industry compels the owner of a factory to increase the working capacity of it, and the nature of the manufacture to important changes in the arrangement of the works. It is only a few years ago that the home market for white sugar was universally bad, but the order of the day is now the more rational mode of manufacture, the extraction of raw sugar and the production for the World's market. The consequence of

this is, that vacuum pans are in demand which correspond to the changes in the position of the manufacture, those having 30 square metres of heating surface, and a capacity of 100 metrical centals are considered small, so that those are now required, which have a larger capacity and heating surface.

Vacuum pans with a large heating surface and capacity are now used in many factories, one of which I will describe. The calender or belt is from 2 to 3 metres high, having a diameter of 2 to 2·6 metres or more, and provided with 4 copper coils, each having a diameter of 80 or 100 m/m. The diameter of the calender or belt is confined to the above dimensions on account of the lower part which is made in the form of a cone, the sides of which have an angle of 45° to allow of an easy discharge of the strike.

In consequence of the bottom of the pan being made conical, the steam coils occupy most of the space, leaving little or no room for the charge, so that this must be provided for at the top, by the arrangement of the steam coils in the bottom, it is with difficulty that a stiff course grained strike will fall, the height of the mass in these pans will be as much as 3 metres, so that notwithstanding their large dimensions and great height, they have a very small vapour space when they are full; there are pans made with a large vapour space, several of which I have seen with a height of 1 metre above the ordinary level of the mass, for the purpose of supplying the maximum charge for which it is constructed. There are vacuum pans which have a heating surface of 30 to 40 sq. metres, and can contain a charge of 100 to 150 metrical centals. How would a vacuum pan look with 60 to 100 sq. metres of heating surface and a charge of 200 to 300 metrical centals.

As it has already been shown, as regards vacuum pans, the fault lies in this, that we cannot emancipate ourselves from the cylindrical form, and serpentines of large diameters (Plates 4 and 5) represent a vacuum pan constructed on the same principle as the Wellner-Jelinck evaporation apparatus; having a heating surface and capacity for a charge of 300 to 400 metrical centals, without exceeding the ordinary dimensions.

This vacuum pan is especially designed for being heated with exhaust steam or the vapour from other juices; it has a high vapour space and a low boiling level with a

large charge ; if a full charge is supplied it will only be about 0·1 to 0·12 metres above the top row of tubes. The heating surface consists of small brass tubes, having an external diameter of about 25 to 27 m/m, by these being of a small diameter a large heating surface can be obtained in a small cubic space, the small diameter presents no obstacle to the free discharge of the strike, as the tubes of 80 to 110 m/m diameter do, and the space between them being only 100 to 150 m/m for providing the heating surface ; the tubes are placed directly above each other, and permit of a free discharge of the strike, the heating arrangement is further so constructed, that a large grained sugar can be made at pleasure, and boiled as long as desired.

The tubes are placed in 2, 3, or 4 rows, according to the size of the vacuum pan, and heated separately, if desired, with vapour, exhaust, or direct steam, and to shut either of them quite off, it is completely under control to gradually increase the concentration of the juice with the lower stage of tubes, and to set the upper stage to work as the quantity increases ; the influence this gives to the granulation, every sugar maker can answer.

If the vacuum pan is supplied with hot vapour the copper tubes are destroyed ; this has occurred in factories where they have applied this rational system of finishing sugar boiling. This danger is avoided in this type of vacuum pan as the tubes are made of brass.

What the advantages are in using the vapour for finishing the boiling, will be shown in considering the evaporation plant in general. To use the new form of vacuum pan apparatus in the place of the cylindrical type with a conical bottom, the complete discharge of the masse cuite must be considered, this is carried out by a right and left hand screw (which is distinctly shown in the lithograph plate 5), which brings the last of the charge to the outlet valve. This arrangement did not answer, so that two discharge cones fitted with valves must be used, which work with entire satisfaction ; the two discharge cones are heated by steam in the spaces P, P, P, so that it is possible to boil to the bottom of the pan where there are no tubes. In practice this has given complete satisfaction ; it is needless to add more, as the practical sugar maker can by considering and weighing what has been said, form his own opinion.

D.—THE EVAPORATION PLANT IN GENERAL.

In order to avoid making these lines too complicated, I do not wish to criticise the existing evaporating plant; we will only go over the working of it, pencil in hand, in order to see where alterations are needed.

As I have already mentioned, I understand not only the evaporating plant but the placing together of two or more evaporating vessels. As the heart is to the human body, so in a narrower sense is the evaporating plant to the sugar factory; a correct function of the heart is not alone sufficient for a correct circulation of the blood in the human body, in that the same is only one member of the blood circulating apparatus, but there must also be a correct function of all the arteries and veins, it is also not sufficient if the evaporating vessels, as such can work correctly, but the arteries and veins of the sugar factory must do so, that is to say, all that belongs to the mutual working of the evaporating plant must be in unison with itself.

On this ground, I shall not keep strictly to the title of this part, but shall make everything contribute to attain the object in view which I may require. If later I make reference to the boiler house, it must be understood that this belongs to the subject in hand.

First, I shall specially treat on the consumption of steam and feed water in the sugar factory. The consumption of feed water in the boilers will be the basis on which to control the evaporating plant, and each working arrangement which is connected, or can be brought into connection with them.

The consumption of steam in a sugar factory required to work 100 metrical centals = 10,000 kilos of Beet into raw sugar by means of diffusion.

	kilos of liquid.	calories.	kos. steam.
(*a*) Diffusion. The quantity of water drawn off after diffusion is accomplished: will be 12,000 kilos, having a temperature of 20°C - - - -	-	= 240,000	
Further there is drawn off 8,000 kilos lixiviat parts at a heat of 20°C - -	-	= 160,000	
Drawn off for Diffusion or re-heating about 180% of juice from the weight of Beet, thus 18,000 kilos at 30°C - -	-	= 540,000	
Consumption of heat by the diffusion -	-	940,000	
This gives 1,480 kilos steam, in round numbers - - - - -	- -	- -	1,500
It is assumed that the water in the factory is 0° Cels., and the heat existing and remaining in the diffusion battery is only once developed. The diffusion water is heated directly by the in-flowing steam.			
(*b*) First carbonatation—For 1st carbonatation there is 18,000 kilos diffusion juice, which has to be heated from 30° to 90° Cels. - - -	-	1,080,000	
Further, by adding 3% of the weight of the beet in lime. and 1,840 kilos of lime milk at 15°B., which has to be heated from 0° to 90°C. - - - - - -	-	165,600	
Total - - -	-	1,245,600	
For the evaporation in round numbers	- -	- -	2,280
(*c*) Second carbonatation; thin juice, filtration of thick juice,* raising of juice by means of montjus and the animal charcoal.			
There is from the 2nd carbonatation, and filtration to heat all the thin juice -	18,000		
The water of the milk 1840 (lime milk.) — 300 (milk.) -	1,540		
Total - - -	19,540		
These 19,540 kilos of liquid have to be re-heated to 25° Cels., requiring - -	-	488,500	
Further, by adding 12% of the weight of beet in animal charcoal, the water required for washing it is 1½ times, thus, 18% of the weight of beet - - - -	1,800		
For washing the filter press deposit, and 8% of the weight of beet in deposit, will require 70% of its weight of water -	560		
Carried forward - - - -	2,360	488,500	3780

* The thick juice has not been taken into consideration, as when it reaches the charcoal filters it is at a high degree of concentration, and attains a dark colour, and a heat of about 65 degs. Cels. The specific heat is left out.

	kilos.	calories.	kilos steam.
Brought forward - -	2,360	488,500	3,780
These 2360 kilos water are to be heated from 0° to 100° *Cels*.. - - - - -		236,000	
Total - - - -	2,360	724,500	= 1,360
For the deposit of montjus, thin juice montjus, thick juice montjus, and the *twice* 12% animal charcoal, 70 cub. metres steam at a pressure of 2½ atmospheres are required ; in round numbers - - - - - - - -			140
(*d*) Evaporation. By Diffusion 18,000 kilos of juice of about 9% Balling to be evaporated to 50% Ball. The water to be evaporated :—			
*$W = 18{,}000\ (1 - \frac{9}{50})$ - - - - - -	14,760		
Further the water from the lime milk -	1,540		
The washout water from the charcoal filter, which was in the juice - - -	600		
The washout water from the filter press deposit - - - - - - - -	500		
Total - - -	17,400		
If these 17,400 kilos be evaporated by *Double Effet, then there is required* $\frac{17{,}400}{1 \cdot 96}$ in round numbers - - - - - - - - - -			9,000
(*e*) Finishing boiling in vacuum pan. There is to be understood the boiling out of the charge, and the boiling of the after product.—As in the molasses there remains only ¾% water of the weight of Beet, it can be calculated that in the vacuum pan the rest of the water contained in the thick juice must be evaporated.			
There is of thick juice . . 18,000—14,760 = 3,240 kilos ; there is therefore : $W = 3{,}240$ kilos (1—50/100) to evaporate -	1,620		
Carried forward - - - - -	1,620		14,280

* For speedy calculation of the thin juice to the thick juice, charge, &c., and inversely I use the following simple formula :—

$$K_1 = \frac{K_2 S_2}{S_1}\ ;\ S_2 = \frac{S_1 K_1}{K_2}\ ;\ S_1 = \frac{K_2 S_2}{K_1};\ K_2 = \frac{K_1 S_1}{S_2}\ \&\ W = K_1\left(1 - \frac{S_1}{S_2}\right)$$

Here K_1 = Weight in kilos of the light juice.
S_1 = Specific weight of Sugar.
K_2 = Weight of thick juice.
S_2 = Specific Weight of Sugar.
W = Water to be evaporated in kilos.

	kilos.	calories.	kilos steam.
Brought forward - - - - -	1,620		14,280
To this must be added the water contained in the thick juice from the filter, and the washing of the filter, before it goes into the thin juice, as well as the water which is used at the centrifugals - -	180		
Total - -	1,800	kilos water	
to be evaporated in the vacuum pan. As this takes place in a Simple Effet, there is required $\frac{1,800}{0.9}$ = - - - - - - - - - -			2,000
(*f*) Steam engine. For driving the same there is at least 30 kilos steam required per horse power per hour, and for working 10,000 kilos of beet-root per hour a steam engine of about 150 horse power is required, therefore the consumption of steam will be - - - - - - - - - - - - -			4,500
(*g*) On loss through heat radiation and condensation in conducting the steam - - - - - - - - - - - - -			520
Total consumption of steam - - - - -			21,300
The whole of this steam, however, is not to be generated in the boiler, as the exhaust steam of the steam engine is used for evaporating, which is - - - - - - - - - -			4,500
Therefore there remains for the boiler - - -			16,800

Or, in other words, the steam the boilers have to supply is 168% of the weight of Beet, which means 168% feed water for the boiler.

On an average evaporation of 6 kilos of water per kilo of coal, will give a coal consumption of 27·8% of the weight of the Beet. To make this very clear, I recapitulate the whole consumption of steam in percentage of the quantity of Beet worked up:—

(*a*) For diffusion - - -	15·0%
(*b*) For carbonatation - -	22·8%
(*c*) For 2nd carbonatation, filtration, and raising the juice -	15·0%
(*d*) Evaporation 90—45 - -	45·0%
(*e*) Finishing boiling in vacuum pan - - - - -	20·0%
(*f*) Steam Engine - - -	45·0%
(*g*) Loss, &c. - - - - -	5·0%
Total	168·0%

This expresses the steam in percentage of the quantity of Beet worked, and which must be generated by the boilers. The exhaust steam from the engine has been taken into account.

This comparison gives the steam consumption, corresponding to practical working results,* and should vary very little in different factories; for general use it will be correct, and will at the same time serve as a guide in looking for possible economic savings. The two values, *d* and *e*, form the chief factors, namely, the evaporation and the vacuum pan, which together equal a steam consumption of 65% of the weight of Beet and 10·8% of coal. Now comes the task of reducing the consumption of coal to a minimum.

If, for the evaporation of the thin juice, we employ a Triple Effet instead of a Double Effet, 1 kilo of steam will evaporate 2·85 kilos of water, the consumption of steam will be $\frac{17,400}{2 \cdot 85} = 6,105$ kilos, or 61·00% of the Beet.
Exhaust steam to be deducted. 45·00
Consumption of direct steam - 16·00% „ „

Therefore, by using a Triple Effet the saving is 45—16= 29% of the weight of Beet in direct steam, and 29% of feed water, or about 5% of coal on the weight of Beet, or 20% of the amount of coal used.

If we take a Quadruple Effet for the evaporation, there will only be required $\frac{17,400}{3 \cdot 79}$ or in round numbers 4599 kilos steam, or of the weight of Beet - - - - 45·9%
Deduct from this the exhaust steam from the engine 45·0%

There will be no direct steam required for the evaporation of the thin juice.

The saving is equal to 45% of feed water, or 7·5% of coal on the weight of Beet or 27% of coal consumption.

If a Quintriple Effet is used there will be required $\frac{17400}{4 \cdot 72} = 3,700$ kilos of steam or - 37·1% of the weight of Beet.
Exhaust steam - - - 45·0%

Giving an excess of - - 8·0% of exhaust steam, *which cannot be used for the evaporation of thin juice.*

* Taken from comparisons in Austria.

This 8% exhaust steam can be used in the vacuum pan, or for the after products in a Double Effet. As 1 kilo of steam in a Double Effet evaporates 1·96 kilos of water, the 8% excess of exhaust steam will evaporate 15·68% of water, of the weight of beet in the vacuum pan; in this case it is only necessary to add 4·32% of direct steam, which, however, is again reduced to 2·3% by boiling in a Double Effet vacuum pan.*

So that in the last case the consumption of direct steam is as follows :—

(*a*)	For diffusion unaltered	- -	15·0%
(*b*)	,, 1st Carbonatation	- -	22·8%
(*c*)	,, 2nd ,, and filtration unaltered	- -	15·0%
(*d*)	,, Evaporation of thin juice	-	0·0%
(*e*)	,, finishing boiling	- -	2·3%
(*f*)	,, Steam engine	- - -	45·0%
(*g*)	,, Loss, etc.	- - - -	5·2%
	Total	- -	105·3% steam

Or 105·3% feed water, or $\frac{105 \cdot 3}{6} = 17 \cdot 6$% coal. This is equal to a saving of 10% of the weight of Beet worked, or nearly

* It will strike many readers of this, that as so much direct steam is used in a Double and Triple Effet, and in a Quintriple Effet and a Double Effet vacuum pan a further 2·3 per cent. of direct steam is required to finish boiling the sugar, whilst in manufactories the thin juice can be jointly evaporated without the application (!) of direct steam; the explanation of this is given as follows:

1. In such factories the evaporating apparatus rarely evaporates to 50 per cent. Balling, as the vacuum pan must effect the concentration above this point.

2. The discharge from the serpentines which are heated by direct steam, generally go into the exhaust steam receiver, either direct or by passing through the closed water receiver or the automatic traps. The whole of the excess of direct steam that is not condensed will assist the exhaust steam with which it mixes, also the excess of the heat of the condensed water.

3. A minimum consumption of 30 kilos of steam per hour per horse power is assumed for the steam engine, and in most factories 40 kilos and more are required, according to the economical working and back pressure of exhaust steam given to the engine. This last gives an increased consumption of direct steam as it passes through the steam cylinder first, and therefore cannot pass the direct steam valve of the vacuum pan or the evaporation apparatus.

This, however, has no influence on the result of the calculation, so long as the exhaust steam can be applied for the evaporation as is seen from the following :—

(*a*)	For Diffusion	15·0	per cent.
(*b*)	,, 1st Carbonatation	22·8	,,
(*c*)	,, 2nd ,, filtration, etc. ...	15·0	,,
(*d*)	,, Evaporation 90—60	30·0	,,
(*e*)	,, Finishing boiling	20·0	,,
(*f*)	,, Steam engine if 40 kilos per horse power and per hour is taken	60·0	,,
(*g*)	,, Loss of heat	5·2	,,
	Total as before	168·0	,,

40 % of the coal hitherto used. This saving is possible with imperfect boilers and moderate coal; if the evaporation of the water is increased to 7·5 kilos instead of 6 kilos per kilo of coal consumed which we have calculated, this will give $\frac{105.6}{7.5} = 14\%$ of coal for the weight of Beet, not only on paper but in practice. It is, however, not acknowledged that such an arrangement of an evaporating plant by its size, influences the final balance as it does that of the coal. What the sugar maker has to decide is the necessary increase of capital, paying interest, and to redeem it, so that what he saves he is not obliged to give to the boiler maker.

We have seen from the foregoing the great advantages of the Multiple use of the heat of steam, also a way which tends to the desired end—economy of coal. Let us now try to find another way in the same course, but in a different direction, and see whether it be possible to follow it and obtain any advantage. Take as the basis for further consideration 10,000 kilos of Beet to be worked per hour.

(*a*) Diffusion. For the diffusion of 10,000 kilos of Beet there is required, as shown, 940,000 calories, or 1,500 kilos of steam to heat the Beet chips and the diffusion water which enters the battery at 0° C, and the condensed water from the evaporating apparatus is used for the diffusion instead of from the well or the river, so regulating the condensed water that it is discharged at 30° C., this being the most economical temperature, if the liquid boiling in the last vessel should be at 60° C., this condensed water can enter the diffusion battery at 20° C, if it be re-heated by the vapour from the third vessel of the Triple Effet before entering the battery, it will easily attain a temperature of 35° C, and if, for the diffusion products, 980,000 calories are used, which is all they can take up, the only heat to be provided for is that which is lost by cooling on the sides of the battery, likewise the initial heat which is translocated in the diffusion, which taken together is not 33% of the whole heat. There is, therefore, a saving of at least ⅔rds of the whole heat, equal to about 600,000 heat units, or 1,000 kilos steam, so that there remains to be provided 500 kilos of steam, equal to 5% of the weight of

Beet. The surface of the re-heater for this is calculated as follows :—

To heat 28,000 kilos of water from 20° to 35° C. the heating steam at 60° C, the transmission co-efficient is practically 5, there is consumed

28,000 × 15 = 420,000 W.E. heat units per hour, or 7000 units per minute.

$$F = \frac{7,000}{5\left[60-(20+\frac{15}{2})\right]} = 43 \text{ sq. metres.}$$

The counter current re-heater should be used for this, it is of a similar construction to the counter current coolers. (For which see Plate No. 9). It never fails in doing its work and the tubes are easily cleaned, and the desired degree of heat can always be attained,* as the current of the steam as well as the current of water arise from a right principle, which is not the case in the present tube re-heaters with vertical tubes.

(*b*) Carbonatation. It is here assumed that 18,000 kilos of juice comes from the diffusion at 30° C., which should be heated to 90° C before being supplied to the carbonatation tanks, also 1,840 kilos lime water from 0° to 90° C.

These 18,000 kilos of juice can also immediately be heated to at least 20° C by means of a counter current re-heater, supplied with the vapour from the third vessel, before it enters the carbonatation tanks, which will require 360,000 calories = 670 kilos steam or 6·70% saving of steam of the weight of Beet. The size of an ordinary heater with a transmission co-efficient of 4 would be :

$$F = \frac{6000}{4(60-(30+\frac{20}{2}))} = 75 \text{ square metres.}$$

The question now is whether we have a sufficient number of calories of latent heat at our disposal.

From what has been said we see that the evaporating apparatus can evaporate 17,400 kilos of water. A Triple Effet would therefore have to evaporate in the third vessel, $\frac{17400}{3}$ = 5,800 kilos of water, thus providing = 5,800 kilos of vapour at 60°, which gives 564 units of heat for 1 kilo of steam, latent heat. These 5,800 × 564 = 3,271,200 W.E. heat units, whilst we require for the whole of the diffusion

* In this case also the transmission co-efficient would be greater and the heating surface of the re-heater proportionally less.

water and carbonatation juice, only 420,000 + 360,000 =780,000 W.E. heat units, which is scarcely 25% of the above amount.

There is also a saving of direct steam in—

(*c*) The second carbonatation and filtration by employing the condensed water and re-heating it by means of the vapour for the purpose of washing the filters and filter deposit, this saving is $\frac{1}{3}$ of the quantity of steam mentioned, viz.: $\frac{15}{3} = 5\%$. Therefore, only 10% direct steam is required instead of 15%.

(*d*) *The evaporation.*

(*e*) The vacuum pan.

These two apparatus can be easily united into one, as follows:—By means of the Triple Effet the juice is evaporated to 50% Balling, and the filtered juice to 63% Balling, and then finished in the vacuum pan. To put this into practice the third vessel of the Triple Effet is divided into two vessels, a large and a small one, in the larger body the juice would be evaporated to 50% Balling; then to the filters after filtration it would be returned to the smaller vessel to be concentrated to 63% Balling, and then to the vacuum pan.

The steam required in this case would be as follows:—

The water in 18,000 kilos juice from 9° to 50% Bg. - - - - - - - - =	14,760	kilos of water.
The water in the lime milk and washing - - - - - - =	2,640	
The water in 3,240 kilos of syrup 50% to 63% = 3,240 (1—50/63) - =	668	
The wash water in the thick juice filter - - - - - - =	180	
Total - -	18,248	„
To evaporate this water by a Triple Effet, there is required $\frac{18,248}{2\cdot85}$ = 6,403 steam - - - - -	64%	of the weight of Beet.
Against this there is the exhaust steam from the steam engine -	45%	„
Required direct steam -	19%	„

The vacuum pan has to boil to masse cuite 3,240—668 =2,572 kilos of syrup of 63% Balling, from which there is 2,572 (1—63/100)=951 kilos of water to be evaporated, and will require in round numbers 1,000 kilos steam or 10% of the weight of Beet.

In all there will be required—

(*a*) For diffusion - -	5·0%	of the weight of Beet in steam.	
(*b*) For carbonatation - -	16·0%	,,	,,
(*c*) For 2nd carbonatation, filtration, &c. - -	10·0%	,,	,,
(*d*) For evaporation - -	19·0%	,,	,,
(*e*) For the vacuum pan- -	10·0%	,,	,,
(*f*) For steam engine - -	45·0%	,,	,,
(*g*) For loss, &c. - - -	5·2%	,,	,,
Total consumption of steam -	110·2%	,,	,,

Or 110·2% of feed water for the boiler, by 6 fold evaporation, there will be required $\frac{110{\cdot}2}{6}=18{\cdot}33$ kilos coal per 100 kilos Beet or 10% coal per hectolitre juice.

Combinations of the use of heat are in many ways possible, and will not be considered in detail, but given in the tables on following pages, any one can look up the combination which best suits his circumstances.

The excess of exhaust steam which is not used in the carbonatation can be used in any of the other apparatus which require steam.

From the Tables B, C, and D, it will be seen that it amounts to the same, whether more or less steam is used for the engine, as the excessive use of direct steam is reduced by using the exhaust steam. This, however, is only right so long as the exhaust steam can be used. As soon as this is not the case, then there is a loss, as will be seen from the following Tables.

Of the loss in Tables A, B, C, D no further notice is taken. It is self evident that the same increases in the total when more steam is used for the engine.

I. MULTIPLE EVAPORATION without utilising the vapour condensed in the last vessel.

A.—ENGINE, CONDENSING, & WORKING WITH EXPANSION.

Steam consumption per hour per horse power 16 kilograms.

	Evaporated by	Double Effet.	Triple Effet.	Quadruple Effet.	Quintuple Effet.	Remarks.
Consumption of steam in percentage of quantity of Beet worked up.	Steam Engine[1] - -	24·0	24·0	24·0	24·0	[1] In this and all the following tables there is taken as a basis, 10,000 kilos Beet to be worked off, and a juice extraction of 180% of the weight of Beet. Evaporation is effected from 9 to 50% Balling before filtration, then filtered, and in the last vessel evaporated to 63% Balling, then passing to the vacuum pan
	Evaporation - - -	93·0	64·0	48·0	38·0	
	Vacuum Pan - - -	10·0	10·0	10·0	10·0	
	Diffusion - - - -	15·0	15·0	15·0	15·0	
	Carbonatation - -	22·8	22·8	22·8	22·8	
	2nd do. filtration, &c.	15·0	15·0	15·0	15·0	
	Loss, &c. - - - -	5·2	5·2	5·2	5·2	
	Total - - - -	185·0	156·0	140·0	130·0	

B.—HIGH PRESSURE ENGINE.

Consumption of Steam per horse power and per hour 30 kilos without back pressure.

	Evaporated by	Double Effet.	Triple Effet.	Quadruple Effet.	Quintuple Effet.	Remarks.
Consumption of Steam in percentage of quantity of Beet worked up.	Steam Engine - - -	45·0	45·0	45·0	45·0	
	Evaporation[1] - -	48·0	19·0	3·0	0·0[2]	[1] After allowing for the exhaust steam of the engine
	Vacuum Pan - - -	10·0	10·0	10·0	3·0	
	Diffusion - - - -	15·0	15·0	15·0	15·0	[2] There is already an excess of exhaust steam of 7%. The same will be used in the vacuum pan and allowed for.
	Carbonatation - -	22·8	22·8	22·8	22·4	
	2nd do. filtration, &c.	15·0	15·0	15·0	15·0	
	Loss, &c. - - - -	5·2	5·2	5·2	5·2	
	Total - - - -	161·0	132·0	116·0	106·0	

C.—HIGH PRESSURE ENGINE

With ½ atmosphere of back pressure in the exhaust steam receiver, therefore a consumption of Steam of 35 kilos per horse power and per hour.

	Evaporated by	Double Effet.	Triple Effet.	Quadruple Effet.	Quintuple Effet.	Remarks.
Consumption of Steam in percentage of quantity of Beet worked up.	Steam Engine - - -	52·5	52·5	52·5	52·5	
	Evaporation[1] - - -	40·5	11·5	—[2]	—[3]	[1] After allowing for the exhaust steam.
	Vacuum Pan - - -	10·0	10·0	5·5	—	[2] 4·5 % excess is used in the vacuum pan and allowed for.
	Diffusion - - - -	15·0	15·0	15·0	15·0	
	Carbonatation - - -	22·8	22·8	22·8	18·3	[3] 14·5 excess. Allowing 10 % to vacuum pan, and 4·5 % to carbonatation where it is utilised.
	2nd do. filtration, &c.	15·0	15·0	15·0	15·0	
	Loss, &c. - - - -	5·2	5·2	5·2	5·2	
	Total - - - -	161·0	132·0	116·0	106·0	

D.—HIGH PRESSURE ENGINE.

Consumption of Steam 30 + 10 kilos on account of the back pressure of 1 atmosphere in the exhaust steam receiver = 40 kilos per hour per horse power.

	Evaporated by	Double Effet.	Triple Effet.	Quadruple Effet.	Quintuple Effet.	Remarks.
Consumption of steam in percentage of quantity of Beet worked up.	Steam Engine - - -	60·0	60·0	60·0	60·0	
	Evaporation[1]) - - -	33·0	4·0	—[2])	—[3])	[1]) After allowing for the exhaust steam.
	Vacuum Pan - - -	10·0	10·0	—	—	[2]) 12% excess of exhaust steam of which 10% to vacuum pan and 2% in carbonatation.
	Diffusion - - - -	15·0	15·0	15·0	15·0	
	Carbonatation - - -	22·8	22·8	20·8	10·8	
	2nd do. filtration, &c.	15·0	15·0	15·0	15·0	[3]) 22% excess of exhaust steam, to be utilised 10% by vacuum pan and 10% by the carbonatation.
	Loss, &c. - - - -	5·2	5·2	5·2	5·2	
	Total - - - -	161·0	132·0	116·0	106·0	

II.—MULTIPLE EVAPORATION which utilises the heat of the vapour of the last vessel for heating in a re-heater the diffusion water and juice before it goes to the carbonatation tanks.

A[1]) EXPANSION ENGINE

With Condensation. Consumption of Steam 16 *kilos.*

	Evaporated by	Double Effet.	Triple Effet.	Quadruple Effet.	Quintuple Effet.	Remarks.
Consumption of Steam in percentage of quantity of Beet worked up.	Steam Engine - - -	24·0	24·0	24·0	24·0	[1]) I pass over the table B for an Engine with a consumption of 40 kilos steam, as the final results are the same as in the following table C.
	Evaporation - - -	93·0	64·0	48·0	38·0	
	Vacuum Pan - - -	10·0	10·0	10·0	10·0	
	Diffusion - - - -	5·0	5·0	5·0	5·0	
	Carbonatation - -	9·2	9·2	9·2	9·2	
	2nd do. filtration, &c.	10·0	10·0	10·0	10·0	
	Loss, &c. - - - -	5·2	5·2	5·2	5·2	
	Total - - - -	156·4	127·4	111·4	101·4	

C.—HIGH PRESSURE ENGINE

Consumption of Steam 40 *kilos* + 7 *kilos for the* ½ *atmosphere of back pressure in the exhaust steam receiver.*

	Evaporated by	Double Effet.	Triple Effet.	Quadruple Effet.	Quintuple Effet.	Remarks.
Consumption of steam in percentage of the quantity of Beet worked up.	Steam Engine - - -	70·0	70·0	70·0	70·0	[1]) After allowing for the exhaust steam.
	Evaporation[1] - - -	23·0	—[2])	—[3])	—[4])	[2]) *6 per cent. excess of* exhaust steam taken off by the vacuum pan.
	Vacuum Pan - - -	10·0	4·0	—	—	
	Diffusion - - - -	5·0	5·0	5·0	5·0	[3]) 22 per cent. excess exhaust steam, divided 10 per cent. to vacuum pan, and 12 per cent. at pleasure, the amount deducted at the end.
	Carbonatation - -	9·2	9·2	9·2	9·2	
	2nd do. filtration, &c.	10·0	10·0	10·0	10·0	
	Loss - - - - - -	5·2	5·2	5·2	5·2	[4]) 32 per cent. excess exhaust steam, there is 10 per cent. to deduct for vacuum pan and 22 per cent. from *the total, according* as it has been divided
	Total - - - -	132·4	103·4	99·4	99·4	
	Above saving deducted - - -			12·0	22·0	
	Actual consumption	132·4	103·4	87·4	77·4	

D.—HIGH PRESSURE ENGINE.

Consumption of steam 40 *kilos*, + 13 *kilos for the* 1 *atmosphere of back pressure in the exhaust steam receiver.*

Consumption of steam in per centage of quantity of Beet worked up.

Evaporated by	Double Effet.	Triple Effet.	Quadruple Effet.	Quintuple Effet.	Remarks.
Steam Engine - - -	79·0	79·0	79·0	79·0	
Evaporation[1]) - -	14·0	—[2]	—[3]	—[4]	1 After allowing for the exhaust steam.
Vacuum Pan - - -	10·0	—	—	—	2 15 per cent. excess of exhaust steam, 10 per cent. to deduct from vacuum pan, and 5 per cent. from the total.
Diffusion - - - -	5·0	5·0	5·0	5·0	
Carbonatation - - -	9·2	9·2	9·2	9·2	
2nd do. filtration, &c.	10·0	10·0	10·0	10·0	3 31 per cent. excess of exhaust steam, 10 per cent. to deduct from vacuum pan, and 21 per cent. from the total.
Loss - - - - - - -	5·2	5·2	5·2	5·2	
Total - - - -	132·4	108·4	108·4	108·4	4 41 per cent. excess, 10 per cent. to deduct from vacuum pan, and 31 per cent. from total.
From the above saving - - - -		5·0	21·0	31·0	
Balance - - - - -	132·4	103·4	87·4	77·4	5 In this case therefore the back pressure of 1 atmosphere of the exhaust steam is not allowed for as this goes to direct loss.
Exhaust steam not consumed, which is obliged to be let off into the air - - -				1·6[5]	
Actual consumption -	132·4	103·4	87·4	79·0	

These tables are not made with a pretence to mathemetical accuracy, yet they come so near that they can be used with every certainty. They give a correct idea of the steam economy of a sugar factory with various arrangements, and are intelligible to any one.

E.—DESIGNING AND CONSTRUCTING THE EVAPORATION APPARATUS.

Having a given amount of Beet to be worked off per hour, the percentage and density of the juice obtained, and the required degree of concentration; these datas will be sufficient for calculating the size of the evaporating apparatus. To show this is practical, it is only necessary to refer to the example by which the consumption of steam was calculated for a sugar factory. As a basis we will take 10,000 kilos of Beet to be worked off per hour, juice obtained from the diffusion 180% of the weight of Beet, having a density of 9% Balling.

What size must a Triple Effet be to evaporate this juice to 50% Balling.

The water to be evaporated will be:—

From the diffusion juice	$W = 18{,}000\ (1 - \frac{9}{50}) =$	14,760 kilos.
,, lime milk	- - - - - =	1,540 ,,
,, washings from the charcoal filter	=	600 ,,
,, ,, ,, filter press deposit	=	500 ,,
	Total - -	17,400

This is the quantity of water to be evaporated per hour. The dilution of the juice by steam scumming is here not taken into account in the 1st and 2nd carbonatation; this should no longer be used in a well conducted factory.

Taking 18,000 kilos instead of 17,400 in case of an accidental stoppage, there will be 6,000 kilos of water to be evaporated by each vessel per hour, and according to the table on page 128, a Triple Effet, system Wellner-Jelinek, evaporates the theoretical 40 kilos of water per square metre per hour.

If in practice we take 75% of this, which has been proved to be the minimum, then the 6000 kilos are divided by 30, viz.: $\frac{6000}{30}$ = 200 *square metres heating surface for* each vessel, the exhaust steam should have a pressure of $\frac{1}{2}$ atmosphere and 600 m/m of vacuum in the third vessel. A Triple Effet with this heating surface should with the above co-efficient, evaporate the required amount of water,

and yet there will be cases where this is not fulfilled, and certainly then, it will be that the basis of the design and construction are erroneous, which is very often the case in practice.

Confining myself to this remark, I pass at once to presenting the principles of the proper design and construction of the Triple Effet. What is correct for the Triple Effet is naturally correct for an evaporation apparatus of as many vessels as may be desired.

The working capacity of an evaporating apparatus depends chiefly on the amount of difference of temperature between the heating steam and the boiling liquid, and the greater it is, so much greater will be the working capacity of the apparatus. This difference of temperature will be uniform over the whole heating surface if the apparatus is properly constructed, no point must exist in the heating surface where the difference of temperature may be less on account of bad design or construction. To attain this, the pressure of the heating steam must be equal in the whole heating system, and it must not happen that at the steam supply-end of the tubes the temperature of the steam is higher than it is at the discharge end, that is, it must be so regulated that the supply and discharge of the steam and waste water, and the pressure of the heating steam remains the same in all the tubes, and the waste water be discharged at the same temperature as the steam pressure.

Péclet says, in his work—(even in the old edition, 1860,) in reference to the serviceable effect of the heating surface, "that it is advantageous to have a certain pressure in the receiver into which the condensed water flows, and to place a valve at the bottom of it, which opens by means of a float when the water level reaches a certain height." The reader is advised to read the paragraphs 1608 to 1619, (Péclet) carefully.

Those who have read these pages will be convinced, how important it is to make the apparatus of such a construction that it has a like difference of heat on its whole surface, in conformity with an equally high pressure. It is a great error and loss to allow the condensed water to discharge into the atmospheric air from the serpentines, tubes, or other heating arrangements however formed, as in consequence of the continual condensation of the water

the pressure of steam is reduced, also the temperature in each part of the apparatus, from the point of the steam supply *to the end of the serpentine or tube,* where there is only condensed water which is discharged at the temperature of the boiling liquid.

If the condensed water is discharged at the same temperature as the boiling liquid, it is evident (as will be explained hereafter) that the effect of the heating surface will be reduced about 50%.

If, for example, we supply the first vessel of a Triple Effet with steam at a temperature of 106° C, and *the boiling liquid in the first vessel* is 94° C, then the difference of temperature will be 106—94=12° C.

The working capacity of an evaporating apparatus of x square metres heating surface is therefore 12 x if the temperature is maintained at 106° C in the whole heating apparatus, that is, if the steam pressure is also maintained at $\frac{1}{4}$ atmosphere over the whole heating surface, and the *condensed water discharged into a closed water receiver,* it will have a temperature of 106° C under this pressure. If the steam was supplied to the apparatus with a like pressure of 106° C and be so completely condensed, that only condensed water is discharged into the open air, *(which is the case in many factories) the temperature of it* at its exit would be reduced to 94° C, so that in that part of the tubes where the condensation takes place there would only be a temperature of 94° C. This reduction of temperature is in proportion to the reduction of pressure caused by the condensation of the steam, so that the mean difference of temperature of the heating surface is between *106° C and 94° C, and* not 12, but $\frac{106+94}{2} - 94 = 6$. The capacity of this apparatus will therefore not be 12 x but *6 x, or 50% less than that given above. It may,* however, be remarked here, that in this case the condensed water must be extracted by means of a syphon, which will form a partial vacuum in the heating space, or the steam or vapour would have to be forced in, a portion of which would be discharged with the condensed water into the open air at a temperature of 100° C.

If this be the case there is a mean heating temperature of $\frac{106+100}{2}=103$ and the effective difference of temperature will be 103—94=9, the capacity of the apparatus

will then equal 9 x, or only 25% less than in the first case, because the loss of heat is greater, as a large quantity of uncondensed steam is lost.

From these examples it is seen that we have it in our power to a certain limit, to increase the working capacity of the apparatus by increasing the pressure of steam in the tubes.

Generally the engines in our sugar factories work with a back pressure of half atmosphere (having a temperature of 112° C., which must be maintained through the whole heating surface), in the exhaust steam receiver, this should be of the type recommended by Peclét and many other intelligent sugar makers.

At the commencement of my career, which is nearly 30 years ago, I found in the factories in which I practised, closed water receivers, for the purpose of increasing the pressure in the heating arrangements and to give a greater evaporating capacity. The condensed water from the serpentines was taken direct to the boiler, and that from the evaporating apparatus went to the water receiver, in which was maintained a pressure of half atmosphere, and was from time to time driven into an open water receiver. Even now this kind of arrangement is to be found in many sugar factories, and is good in this way, that many factories with a small evaporation apparatus did more work than others with a larger heating surface.

Without steam no evaporation, without a difference of temperature no boiling.

I desire the friendly reader to take the foregoing as an introduction, and to follow me in the detailed paragraphs of the description and uses of the different parts belonging to the evaporating apparatus.

(*A*) THE VACUUM AND STEAM GAUGE.

The vacuum gauge shows us the diminished pressure, whilst the steam gauge makes known the increased pressure, if we take 760 m/m as the normal pressure of one atmosphere absolute.

The ordinary vacuum gauges are of the spring type, the construction of which is so generally known that a description of them can be passed over. The same may be said of the atmospheric pressure gauge. In reference to our treatise, I cannot leave unnoticed, that in an

evaporating vessel the vacuum and steam gauge act alternately, and as a vacuum gauge is damaged by pressure, I recommend to the sugar maker an instrument that can alternately show negative as well as positive pressure, without the mechanism being affected.

A simple two legged gauge glass tube, filled with mercury until the level in both legs shows + or — 760 m/m, showing plainly the highest possible and negative pressures, this can be fitted to a metal plate or a wooden board, and divided at the side of each leg into m/m, so that it can be easily read off.

At the commencement of the working season when all the heating tubes are clean, the transmission co-efficient gives its full effect, and the pressure of the exhaust steam is about ½ atmosphere, it follows according to the table on page 128, that the first vessel will have a vacuum of 112 m/m.

If the heating tubes of the third vessel become incrusted by sediment from the boiling juice the transmission of heat will be less, which will reduce the evaporating capacity of the apparatus in the same amount.

To maintain the full working capacity it is necessary, if the heating tubes cannot at once be cleaned, to increase the difference of temperature by increasing the pressure of the steam.

Let us take a case which frequently happens in practice, viz., that the third vessel shows a vacuum of 21″ English=532 m/m vacuum, equal to an absolute pressure of 760—532=228 m/m., the juice will then boil in a vacuum at about 69·5° C. If we add 1½° of temperature for the higher concentrated sugar solution, we have a boiling point of 71° C. The total temperature would be 120—71=49° C.÷3 will give for one vessel a difference of temperature of 16·3° C., therefore the first vessel would boil at 120*—16·3=103·7° C., corresponding to a pressure in round numbers of 1·15 atmospheres. The vacuum gauge must correspond to the steam gauge and show a pressure of 1·15 atmospheres or about 875 m/m.

It will be seen further on, that not only in consequence of the incrustation of the tubes, but also other circumstances, a higher pressure of steam will be required,

* Temperature of heating steam at one atmosphere.

which will give a difference of the proportion of pressure in the separate vessels, so that it would be advantageous to have a vacuum gauge that will show positive and negative, as before mentioned.

(*B*) THE THERMOMETER.

The necessity of knowing the boiling point of the juice in the apparatus, compels us to place a thermometer to indicate this.

If the boiling liquid was water, a vacuum or steam gauge would suffice, as the boiling point of water is in proportion to the steam it generates. But as sugar solutions have a higher boiling point than water, in proportion to the percentage of sugar they contain, a thermometer is required. It is well known to every sugar maker that the mercurial thermometer, which in this case must be angular, has a very short duration, and the shorter they are the more indistinct the temperature they indicate, metal thermometers act too slowly. The Taloptasimeter has proved to be durable, convenient, and a most practical heat measuring instrument; the Triple Effet should therefore be provided with one of these instead of the ordinary thermometer, notwithstanding its high price.

(*C*) THE SIGHT-GLASS, MAN-HOLE WITH SIGHT-GLASS, & THE GREASE-COCK.

I shall not go into the details of the fittings and mountings, but leave them for future consideration, as they are well known and require no essential improvement. It may at the same time be pointed out that the sight-glasses could be applied to many parts of the evaporating apparatus where there are none, and be of great service, and when possibly the grease cock may be dispensed with.

(*D*) JUICE SUPPLY VALVE.

The juice supply valve is always placed as near as possible to the bottom of the apparatus, and its diameter must be in proportion to the capacity of the apparatus; as to the position of it, it is perfectly correct as recommended. When this cannot be done the valve must be provided with an internal pipe to discharge the juice into the bottom of the vessel, by this arrangement a greater quantity of liquid is evaporated, its movement being so rapid, this has already been mentioned and proved by quoting direct experiments.

The *theory* as well as the practice agree completely one with the other, that is, quickly moving liquid, heats, boils, and evaporates quickly, as the effect of the evaporation of a boiling liquid stands in direct relation with the rapidity of its movement, on this ground nothing should be neglected that can accelerate the movement of the juice. The juice entering the apparatus at the bottom agitates very violently the whole of the boiling mass, and this leads direct to an increase of the evaporating capacity of the apparatus, supplying juice from one vessel to the other causes also a violent movement, not only in consequence *of the elastic force of that liquid which flows into the next vessel, but that the juice* of the foregoing vessel is 15° to 18° higher in temperature than that of the following vessel, in which the boiling point of the liquid is 15° to 18° lower, this gives an immediate development of steam, which is so much the more violent the higher the temperature of the supply juice. The steam bubbles are released with greater rapidity, giving a violent movement to the whole mass, and in consequence a greater quantity is evaporated.

(*E*) THE STEAM VALVES.

Under this head will be discussed the exhaust and direct steam valves of the first vessel. The exhaust steam valve serves to supply the heating arrangement of the apparatus with the exhaust steam from the engine, the waste steam from the serpentines, and other heating and boiling apparatus, and should be large enough to allow the heating steam to pass through it with an average velocity of 30 metres per second.

The quantity of steam to be supplied is found by the formula already given, viz. :—

$$Dg = \frac{Q}{r^2}$$

This *formula* is *indicated* by :—

Dg = The weight of steam in kilos, which can be condensed in the heating tubes of the apparatus.

Q = The number of heat units transmitted per x sq. metre, per minute = FC $(t_2 - t_1)$,

r^2 = The latent heat which is given off by the condensation in the heating tubes = $607 - 0{\cdot}708\ t_2$.

If by the help of this formula the amount of heat is found which an apparatus of the size given is in a condition to condense, then the area of the steam valve in sq. metres will be found by the following formula :—

$$f = \frac{Dg}{30 \times 60 \times 0.8874} *$$

For example, let F=100 sq. metres.

$$(t_2 - t_1) = 17.3$$
$$C = 22$$

It follows that $Q = 100 \times 17.3 \times 22 = 38{,}060$ W.E. heat units.

If $t_2 = 112°$ then $r_2 = 607 - 0.708 \times 112° = 527.7$ and

$$Dg = \frac{38060}{527.7} = 72 \text{ kilos per minute.}$$

The value substituted gives for

$$f = \frac{72}{30 \times 60 \times 0.8874} = 0.045 \text{ sq. metres area.}$$

The diameter of the valve is shown by $d = 240$ m/m.

In this small diameter, no account has been taken for friction, which corresponding percentage must be added.

THE VALVE FOR DIRECT STEAM.

In comparing the steam comsumption of a sugar factory it has been seen that the engine alone never gives the required quantity of exhaust steam for evaporating the Beet juice in an apparatus of multiple working. The better the engines are constructed the more carefully it must be kept in order, so that the consumption of steam may be as small as possible, which will naturally give less exhaust steam, therefore it will always be necessary to use more or less direct steam.

To obtain the necessary supply of exhaust steam, the engine is often worked with a great back pressure. It is quite correct that by this means the capacity of a Triple

---

* 30 = Velocity of steam in metres.
60 = The reduction number per second.
0·8874 = The weight of a cubic metre of steam at ½ atmosphere pressure.

Effet increases in proportion to the pressure of the exhaust steam, but this must have its limits. It is needless here to consider this more closely, as the loss of heat is under control, and by careful consideration of these circumstances it may be decided not to apply too highly compressed exhaust steam, but to supply direct steam into the heating system, instead of into the exhaust steam receiver. Only in such cases where it is wished to apply the vapour from the first or second vessel of an apparatus for heating the vacuum pan or other apparatus, a higher pressure is required in the first, or relatively of the second vessel to obtain the difference of temperature for the apparatus to be heated; in consequence of which the exhaust steam must be more highly compressed. A simple calculation based on local circumstances will give the best explanation in this direction, as to how far this can be carried to obtain actual advantages.

The above has been examined in detail so that the reader may see how often the direct steam valve may be dispensed with when exhaust steam is used. Cases in which a direct steam valve is required will now be taken into consideration.

Take for example a sugar factory using a high pressure steam engine which consumes 35 kilos steam per hour per horse power, and working against a back pressure of half atmosphere.

It will be seen from the comparisons given in Table I c (page 153), that the Triple Effet not only consumes the quantity of exhaust steam discharged by the engine, but also requires 11·5 % of the weight of Beet in direct steam. If there is only the exhaust steam at our disposal the whole percentage of direct steam must be supplied into the steam receiver, or with the exhaust steam into the heating space of the apparatus, until a pressure of half atmosphere is obtained and maintained, in order to keep up the maximum working capacity of the apparatus. If the above 11·5 % of direct steam has to be continually supplied, the steam stop valve must have sufficient area to be able to allow of this quantity and even more to pass through it. I say to be able, because the waste steam from the vacuum pan and other heating coils should always be led into the exhaust steam receiver of the engine, will more than compensate for the 11·5 % of

direct steam; the excess of this waste steam can be used for heating the vacuum pan; when the sugar is thick the valve is opened full, as the sugar in consequence of its high degree of concentration consumes less heat, the greater part of which will pass through the serpentines uncondensed, when this takes place the direct steam valve is shut.

A further case for the application of valves for direct steam is the following :—

Supposing the engine had not more than half atmosphere of back pressure, the vapour from the first vessel of the Triple Effet could still be used to heat some second apparatus which is heated by direct steam; which would save 50 % of steam in each apparatus, which is equal to a Double Effet.

In this case one part of the heating surface of the first vessel should be so arranged that it can be heated through the steam stop valve by steam of three atmospheres pressure; in the Wellner-Jelinck apparatus this is the case. In apparatus of older construction they are assisted by placing a copper coil in the heating arrangement or increasing the heating surface of the first vessel by a circulation tube, the discharge from this should not be led into the general steam receiver, nor direct into that part of the apparatus which is heated by exhaust steam, as the working capacity of the separate heating surface has not the same pressure, one having three atmospheres and the other only half atmosphere, it should be led into a separate water receiver in which there is a pressure of three atmospheres, and is connected to the exhaust steam receiver which has a pressure of half atmosphere by a float valve, the condensed water having a temperature of about 144°C, the excess of heat from it comes in the form of fresh developed steam to the assistance of the exhaust steam, and the divided heating parts attain their proper increased difference of temperature, which will give a corresponding higher working load to the engine by back pressure.

The size of the valve is calculated accurately for this case, according to the formula used for the exhaust steam, by taking as a basis the separated heating surface and other stated factors.

(*F*) EXHAUST STEAM VALVES.—THE AIR VALVES OR AIR COCKS.—THE EXHAUST STEAM RECEIVER AND THE CONDENSED WATER RECEIVER.

These depend on each other in working, so that I shall treat them and their functions together.

Quite as important as the steam supply valves are the valves by which the condensed water from the heating arrangement is discharged, the dimensions of these are decided by the amount of water they have to discharge, which is the same as the weight of the steam supplied in proportion to the heating surface of the apparatus, etc.; it must not be forgotten that the condensed water is mixed with a large quantity of air and other gases, so that it is always recommended to make them larger than is actually required for the water only. The waste water valve is of the ordinary type, and should always be placed at the very bottom end of the heating arrangement, from which a pipe is led to the exhaust steam receiver under the apparatus, the end of this pipe is fitted with a non-return valve, which is lifted by the weight of the condensed water, and at the same time prevents the exhaust steam from escaping from the heating chamber with the waste water; this receiver is generally a cylindrical vessel, arranged either horizontal or vertical, in which there should be maintained a pressure of half atmosphere, or in case of need a higher pressure, it receives the exhaust steam from the engine, the condensed water from the heating and boiling apparatus, viz. :—The serpentines of the the carbonatation, the juice reservoirs, the vacuum pans, and the calorisators of the diffusion, etc. It is provided with a safety valve which is weighted to blow off at a pressure of half an atmosphere, or at any desired pressure, and also permits of an exit of the gases and air the steam brings with it from the boiler, and also serves as a signal that the supply of exhaust steam can be used for other purposes, and to reduce the supply of direct steam.

The water receiver is connected to the front of the heating arrangement, and also to the back, so that it is easy to perceive that in the tubes of the first vessel of a

Triple Effet the steam pressure must be the same as in the exhaust steam receiver, and the condensed water will easily run into it.

The condensed water which accumulates is either pumped direct from it into the boiler by means of a feed pump, or led previously into an open water receiver, where it meets with the vapour water of the vapour pump, and then fed into the boiler, it is fitted with a float valve, which is placed near the bottom, to regulate the discharge of the water.

The air valves which are placed on the back heating chamber of the Wellner-Jelinck apparatus, also at the end of each of the groups of tubes, are for letting out the air which has accumulated before the apparatus is started. When once in full working the steam drives before it the air and gas which are always being developed from the water in the boiler, and carried in with the steam, so that there cannot be any dead space in the tube system, these go into the water receiver from where they must be blown off, the air valves of the 2nd and 3rd vessels lead the gas into the condenser as follows ; the air valve of the 2nd vessel is connected to the heating system of the 3rd vessel where the uncondensed steam mixed with it is used, and the air valve of the 3rd vessel leads direct to the condenser.

The air valves should only serve the purpose of drawing off the noxious gases and air from the heating system of the apparatus, and should never be used to regulate the vacuum in the separate vessels of a Triple Effet. If a Triple Effet be correctly arranged and erected they regulate themselves, it is only to be watched that accidents do not cause trouble, in regulating the vacuum with these valves it causes a great loss of steam. The vacuum of each vessel is regulated by the working of the next, and if the heating surfaces be kept clean so that the steam or vapour is completely condensed, and the vapour connections from one vessel to the other be correspondingly large, so that there can be no back pressure, the condenser and the air pump sufficiently large, the Multiple Effet will work regularly and regulate the vacuum in proportion to the distribution of the heating surface, without any further assistance.

The vapour given off by the juice carries with it various gases, chiefly air, carbonic acid, ammonia, and other decomposing products of the organic condition of the

Beet-juice, the state in which these gases appear, and the kind of gas itself is not sufficiently determined; in consequence, the means of getting rid of them is of a more or less problematical nature, because it is only based on hypothesis. It is, however, certain that there are gases of a special weight, and it is equally so that they accumulate in parts of the apparatus where there is no flow of steam or vapour, for instance in the dead space of an apparatus with vertical tubes.

Some makers of evaporating apparatus are satisfied by explaining it as follows; that these gases are lighter than steam and should be drawn off by various arrangements in the upper part of the heating system; others maintain that the gases must be drawn off at the bottom part of the apparatus, because they are heavier than steam; a third *says if both be done then there is no error.* It will now be considered how far the one or the other is right, and what is to be done.

The mixture of gas will be divided into gases which are lighter and heavier than steam, and presumed to be under a like barometer level and temperature; it is *perfectly well known that the mixture of this gas consists* chiefly of steam, atmospheric air, and ammonia. A glance at a manual of Physics will show that air is heavier, and ammonia lighter than steam, from which it is evident that it would be easy to make an arrangement to draw the ammonia out from the upper part of the heating arrangement, and the air and heavier gases from the bottom part. The conditions of the inside of the heating arrangement which is fed with such a mixture of gases are of so complicated a nature that it would take a long time to sufficiently explain them, and it is certain there will be an explanation when the nature and proportion of the mixture of the gases are understood.

As practice is the mother of knowledge, it is also clear that conditions which actually happen in practice must be estimated by a close observation, and the task of the knowledge is to explain it by continued observation, at the same time it must not be neglected so long as a scientific explanation of it cannot be given.

From a scientific point of view it appears to be absurd to suppose that gases which are found near each other in a space, do not follow the law of diffusion, and

yet practice teaches us that this can happen. For example in Russian sugar factories they obtain carbonic acid for carbonatation from the main flues of the boilers, which are fired with wood, and it is there known to every sugar maker that for the carbonatation suitable gas can only be drawn from the bottom of the flues, as the gas mixture which is moving there contains about 10 to 11 % of carbonic acid, whilst at the top of the flue there is scarcely 4 to 5 %.

If the suction pipe of the carbonic acid pump be placed immediately behind the fire bridge of a bouilleur boiler, and as near as possible to the bottom of the ash-pit, it will draw gas containing 12 to 13 % of carbonic acid, whilst that which passes under the boiler has only about 7 %, from this it will be seen that the carbonic acid, on *account of its great specific gravity*, separates and falls to the bottom, why should not the same and like gases according to their specific gravity, undergo the same process in an evaporating apparatus, if similar conditions offer?

The part in the arrangement of a boiler where a large amount of carbonic acid separates, is where the velocity of the gas is reduced; the same takes place in an evaporating apparatus of the old construction with vertical tubes, where there is a lower velocity of the heating steam, and it is plainly this type of apparatus which shows the greatest fault in this point, and makes it almost absolutely necessary to draw off air and ammonia, if it is not wished to see the working capacity fall to a minimum. Horizontal apparatus of the old construction, with serpentines in which no steam can remain motionless, feel these defects in a smaller degree, whilst the Wellner-Jelinck apparatus only requires the air valves to be opened when starting the apparatus, on account of the uninterrupted velocity of the steam in the tubes; these valves are first used in the vapour receivers for the separation of the gases. These apparently unnatural conditions, which, so to say, give the lie to the law of diffusion of gases, are in my opinion, not in the least unnatural. The gases which arise from the burning of any combustible, or which are disengaged on evaporation, from water in the boiler containing air, carbonic acid, or ammonia, or which arise from the decomposition of the boiling sugar juice, mixed with various foreign organic bodies, are in their origin in

a completely isolated condition, so that the individual infinitively small molecules subsist as independent individuals in close proximity to each other; arranged according to their specific gravities, and the velocity of their movements allow the individual molecules of the various kinds of gas to fall to that level which belongs to it, and it is only after some considerable time that a diffusion can take place, and a uniform mixture originate; if the velocity of these molecules be very great, and their direction often altered, then a separation can not so easily take place, and the whole mixture of gas assumes a certain uniformity.

These conditions take place, more or less, in all evaporating apparatus, and cause trouble, even when these are more or less taken into account, and an endeavour made to prevent their noxious influence. In each case it is best to maintain the heating surface in full work, so that the mixture of steam, condensed water, air, and ammonia, etc., are driven with the greatest velocity *possible through the heating apparatus into the exhaust* steam and condensed water receiver, and here the useful heating steam will be separated from the noxious gases and the condensed water; to effect this the discharge from the first vessel is led into the exhaust steam receiver, as we have already seen. The vapour disengaged from the first vessel heats the second, and is condensed in the heating system of the last, and discharged into the condensed water receiver.

The condensed water receiver is a cylindrical vessel of convenient form, and can be either horizontal or vertical, or rectangular, and made of cast iron, wrought iron being more easily destroyed, this is provided on the top with a stop valve to regulate the inlet of the condensed water, an air valve to regulate the drawing off of the noxious gases and the uncondensed steam, and the bottom with a valve to regulate the discharge of the condensed water to the pump.

The stop valve for the condensed water, uncondensed steam, and the gases carried with them, is connected by a pipe in direct connection with the end of the second vessel; this is not only for discharging the above-mentioned liquids, but in a certain way to regulate the pressure of the heating vapour in the second vessel; as the working of an apparatus is proportional to the similarity of the temperature of the steam to the whole heating surface, it

is easy to perceive that to a certain limit we have it in our power to regulate the working by modifying the pressure in the second vessel; if the stop valve be shut too close the condensed water remains motionless in the heating system of the second vessel, and the tubes become partly filled with water, which puts them out of working; if it be too far opened, too much uncondensed steam will be admitted, so that the pressure in the heating system will be reduced, also the heating surface capacity. This drawback only allows of a partial remedy, by the careful management of the stop valve; it is, however, always troublesome. These faults are found in all condensed water receivers known up to the present. To remedy this inconvenience the receiver should be altered or made in the way shown in Figure 5.

A. Inlet valve for the condensed water.

D. Partition which does not extend to the bottom of the vessel, and forms the chambers B and C, which communicate with each other. They are closed by the condensed water, so that the vapour or steam in the space B cannot mix with the gases, incompletely condensed vapour, or steam in C.

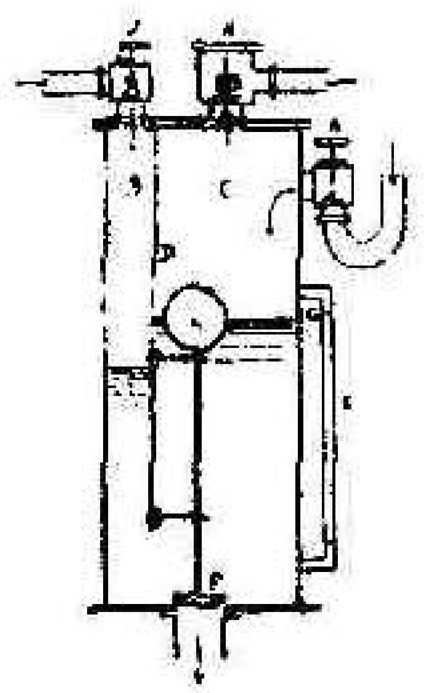


Fig. 5.

E. Ball float, which regulates the valve F and maintains the condensation water at the level G. The valve F leads to the small condensed water pump.

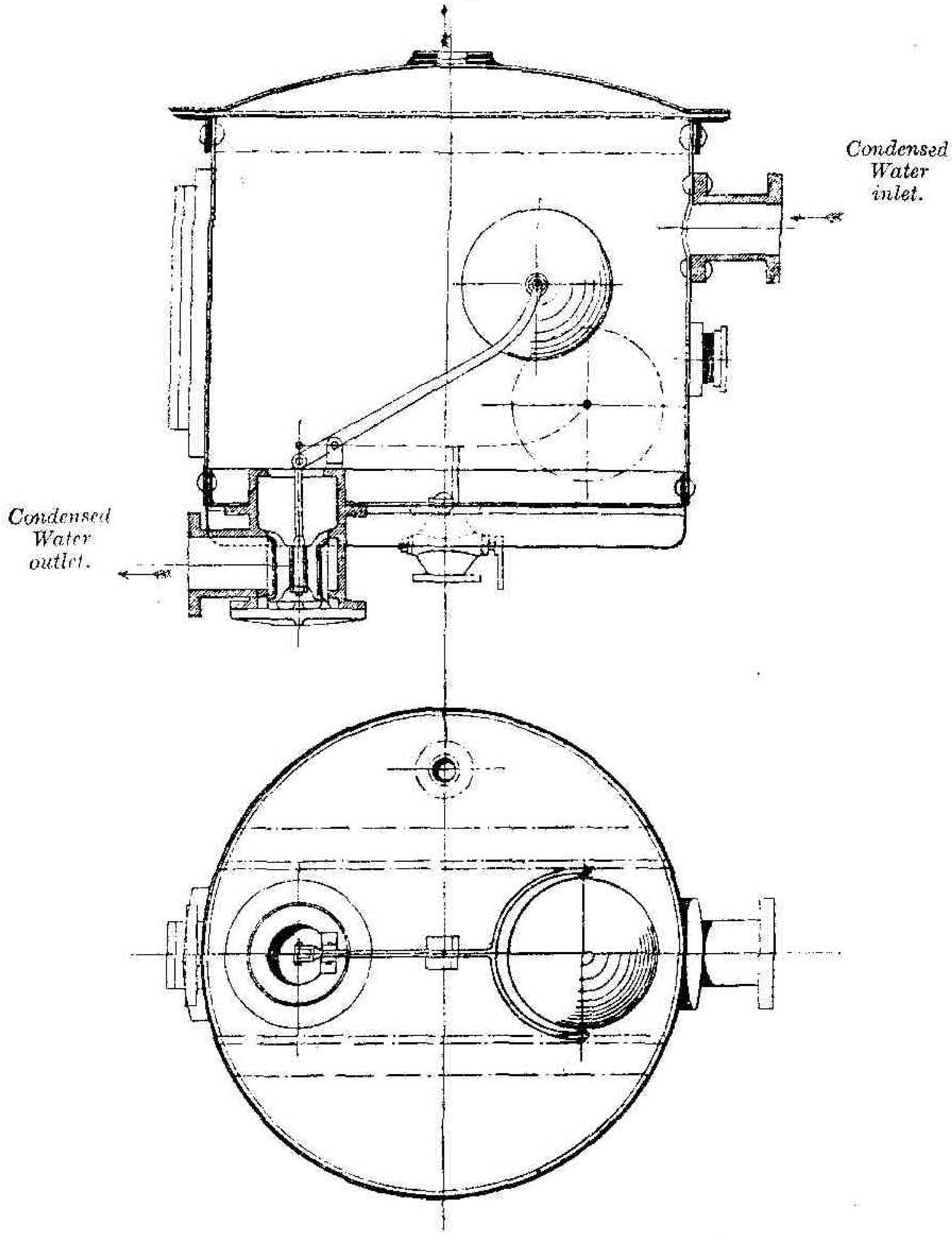
H. A direct loaded valve, which rises when the pressure in the second vessel is too high. This occurs as soon as air or gas accumulates in the space C.

J. An ordinary valve, which forms the connection between C and the chamber B with the front of the steam chamber of the second vessel, and restores the initial pressure of the heating vapour in the whole of the heating system.

K. A water gauge, which shows the proper level of the condensed water.

By the valve H the gases, air, and condensed steam are periodically drawn into the heating system of the third vessel to be condensed as far as possible. There is one of these condensed water receivers between each evaporating

AUTOMATIC
CONDENSED WATER RECEIVER.
Fig. 6.



vessel, and finally the uncondensed gas is drawn from the last receiver into the condenser or air pump.

By this arrangement the heating system of the separate vessels are kept clear of condensed water, and the initial pressure of the vapour is maintained on the whole heating surface, so that the apparatus can work up to its full capacit y.

Figure 6 is a condensed water receiver, designed by the firm of E. Skoda of Pilsen, which works very well.

(*G*) THE CONDENSED WATER PUMPS.

The size of the condensed water pumps is determined by the amount of condensed water to be discharged. The calculation for it is made as for an ordinary water pump. The amount of condensed water to be discharged is easily calculated from what has been shown before, so that it need not be repeated here, at the same time it may be pointed out that placing a check valve on the pump will greatly assist its working capacity, and facilitate the suction of the condensed water at the back of the pump piston. If a condensed water receiver be used as above described, the check valve should be in connection with the space c, and each have a separate pump.

(*H*) THE VAPOUR CONNECTION PIPES BETWEEN THE VESSELS OF THE APPARATUS.

The vapour corresponding to the heating vapour which is developed in each of the vessels of a Triple Effet, has always a diminishing pressure, in consequence of this its volume is always greater than the volume of the steam, in inverse proportion to the pressure. It is of importance to make the connecting pipe of a corresponding size, therefore these from vessel to vessel should be proportionately larger; as the weight of vapour generated in each body is known, and we have given the formula for it, with practical examples, we will only use the following as a guide to obtain the correct sizes. By experience it has been established that the vapour passing through the connection pipe, at a velocity of 60 metres per second, has no pernicious influence, as the counter pressure of the boiling liquid in the previous vessel is not perceptibly increased.

It is advisable not to take the velocity of the vapour higher than 20 to 30 metres per second in the calculation for the diameter of the connection pipe, and 40 to 50 for the last vessel in the apparatus, when it has a very large heating surface, at the sam time not to make the diameter too large on that account. It is natural that in arranging the vapour pipe connections that bends and angles be avoided as much as possible, as these considerably increase the friction of the vapour, and cause a counter-pressure on the liquid, and reduce the vacuum in the previous vessels.

Dg = the weight of vapour produced per minute and per s metres.

q = the diameter of the connecting pipe which has to convey the vapour into the next vessel in metre.

S = the velocity of the vapour per second in metres.

F = the heating surface of the vessel which generates the vapour in sq. metres.

K the weight of a cubic metre of steam at the pressure which corresponds to the vacuum in the vessel.

$$\text{Therefore } q = \frac{FDg}{60\ SKg}$$

', S, and Kg being known, Dg is calculated from ...own quantities given in the calculation for the ...ating apparatus. By substituting the values in the formula the required diameter of the connection will be found. This mode of calculation would ...lly not satisfy the theoretical physicist, but it fully ...s for the object in view, and all practical purposes. ...ief thing is always to take S as small as possible, ... far this should be carried out the result of the ...n itself points out.

(*l*) THE CONDENSER.

...condenser is a very important part of an ...ng plant, as it exercises a decided influence on ...um in the last vessel which determines the good or ...king of the whole apparatus; for this reason it ...e treated more fully.

The condensation of the vapour generated in the last vessel can be carried out in two ways :—

(*a*) By the direct injection of cold water into the vapour.

(*b*) By a surface condenser.

The condensing by means of direct injection can also be effected in two ways :—

(A) Direct injection of cold water on to the vapour, by the application of a particular type of condenser, removing the condensed vapour and water by means of a barometrical pipe, and drawing off the air and gases which are not condensable by means of a dry air pump.

(B) The vapour enters into a condenser, and is condensed by means of an injection of cold water, and drawn off with the condensed water by means of a so-called wet air pump.

Both these are sufficiently known to every sugar maker, and, therefore, do not require a special description, the water enters the condensing chamber through a rose or sieve, to mix as thoroughly as possible with the vapour to effect its condensation.

Whether the first or the last be used in a sugar factory depends on the local conditions, viz. :—

If the factory is not situated too high above the source of water supply, the water soft and clean, and fuel expensive, it will be advantageous to use a wet air pump, by which the separate water supply pump and the whole apparatus for the so-called dry condensation will be saved ; the connecting pipes between the last vessel and the condenser and the condenser and air-pump will be shorter. If, however, the water is not free from mineral substances, and forms deposits, then naturally the condensation should be effected by a barometrical pipe and dry air pump.

It is needless to make further comparisons of these systems as to consumption of fuel and the working expenses. When a dry air pump is used the water for the condensation has to be lifted about 10 metres higher than when using a wet air pump ; this latter has much more work to perform than the former. For the condensation of the vapour there is required 20 to 40 times its weight

in injection water, and the increased cost of fuel is calculated as follows:—In a sugar factory which works 10,000 kilos Beet per hour, there will be in round numbers 18,000 kilos water to be evaporated per hour, and by each of the three vessels 6,000 kilos per hour, being equal to 6,000 kilos of water to be condensed, and taking as an average that it will require thirty times the quantity of water per hour, there will be $6000 \times 30 = 180,000$ kilos of water to be raised 10 metres high, which would require theoretically 6·6 horse power, and by correction, having regard to the loss coefficient, would be 8 horse power.

In the present steam engines which are used in sugar factories, they consume at least 40 kilos of steam per horse power per hour, which represents 320 kilos of steam per hour or by seven-fold evaporation 45·7 kilos of good coal, which would give for condensation by a wet air pump, $\frac{1}{2}$ % more coal to be used for the weight of Beet worked.

If we put into the scale the dry air-pump (not taking into account the water pump), and the other advantages which it gives, we will find by using cheap coal of midding quality that the balance will turn in favour of condensation by it, whereas high priced coal may considerably increase the cost of working. If, in constructing a new factory, high speed engines were used, working with high steam pressure, the consumption of steam can be reduced to 15 kilos per hour, per horse power, which would reduce the consumption of coal in this case in the proportion as 40 : 15, the difference being as follows:—

$$\frac{15 \times 0{\cdot}457}{40} = 0{\cdot}17\ \%\ \text{of the weight of Beet worked.}$$

The water required for condensation being taken at 20 to 40 times the weight of vapour to be condensed, gives the following formula:—

$$q_1 = q\,\frac{550 + t - t_2}{t_2 - t_1}$$

These denote—

q = The weight of vapour to be condensed at a temperature of t.

q_1 = The weight of the necessary injection water at a temperature of t_1.

t_2 = The temperature at which the condensation should take place.

At the commencement of the working season, which is in the warm months, the injection water has a temperature of about 20 Celsius, then $t_1=20$. The temperature t_2 under which the condensation should take place, must be taken at 35° C, as the higher the temperature, so much the more difficult is the condensation and a lower vacuum in the last vessel.

The vapour from the last vessel should have a temperature of 60° C; this has already been taken as the average.

The values being substituted in the above equation will give—

$$q_1 = q\left(\frac{550+60-35}{35-20}\right) = 38\ q$$

Under these conditions the required quantity of injection water is 38 times the weight of the vapour. In winter it is on the contrary, then $t_1=o$, the consumption of water will be much smaller then.

$$q_1 = q\left(\frac{550+60-35}{35}\right) = 16{\cdot}4\ q.$$

That is, 16·4 times the weight of the vapour will in this case be required. In making this calculation the most unfavourable circumstances should always be taken into consideration, and when 38 q is not taken 30 q must be the minimum used.

From the above formula the following will be observed. That the lower the temperature of the water so much the less will be required, and the higher the temperature is of the vapour, so much the more water will be used. These figures, however, only agree theoretically, in practice the consumption of injection water increases according to the type of condenser used.

Condensers in which the injection water cannot spread, and the vapour has not sufficient space or surface to allow it to come in contact with the water, consume considerably more water to effect a perfect condensation; in consequence of this there is a lower vacuum in the last vessel

Here will be pointed out the faults of the condensers at present used, and suggestions made for their improvement.

The great fault in most condensers is that the injection water is supplied by means of a rose, perforated plate or sieve, to produce an artificial rain, under which the vapour is drawn to be condensed. These work well, so long as the holes are not stopped up. When this happens, as it often does, it is necessary to stop several times a day during the working season to clean them, which is early ruin to the condensation arrangement.

It is also seen from this that the water rain surface is too small, and the distance which the vapour travels is too short. Many factories improve the bad condensation as follows; they put a top injection on the condenser which assists considerably, as the course which the vapour and the water travel together in the vapour pipe is considerably longer than in the condensers of ordinary construction.

All the condensers which are constructed for sugar factories have the extraordinary and general fault of being too small, having too small a surface for the condensation of the vapour, which should take place in the condenser, so that there must be sufficient space to allow the vapour time to be condensed by the injection water. For a condensing engine it is the rule that the condenser should have 1·5 times the volume of the air pump, and in evaporating apparatus where the condensation is very much more difficult, the condensers are often found so small that they can scarcely be of any utility. It is advisable when constructing a condenser always to take 1·5 times, or double the volume of the air-pump, as the larger the space is in the condenser the more perfectly will the water separate, giving a much better condensation, and the air pump will work much easier. The result will be a high vacuum in the last vessel, a great difference of temperature in the whole Triple Effet, and the highest working capacity of the apparatus. There is yet to remark, that in designing or constructing a condenser it must be borne in mind that it must stand as near as possible to the last vessel, so that the connecting pipe is as short as possible, which will conduce to a much higher vacuum in the apparatus.

Figures 7 and 8 are condensers which have worked well for several years, in which neither of the inconveniences or faults mentioned are present; they can be used in conjunction with the dry air pump with a little modification.

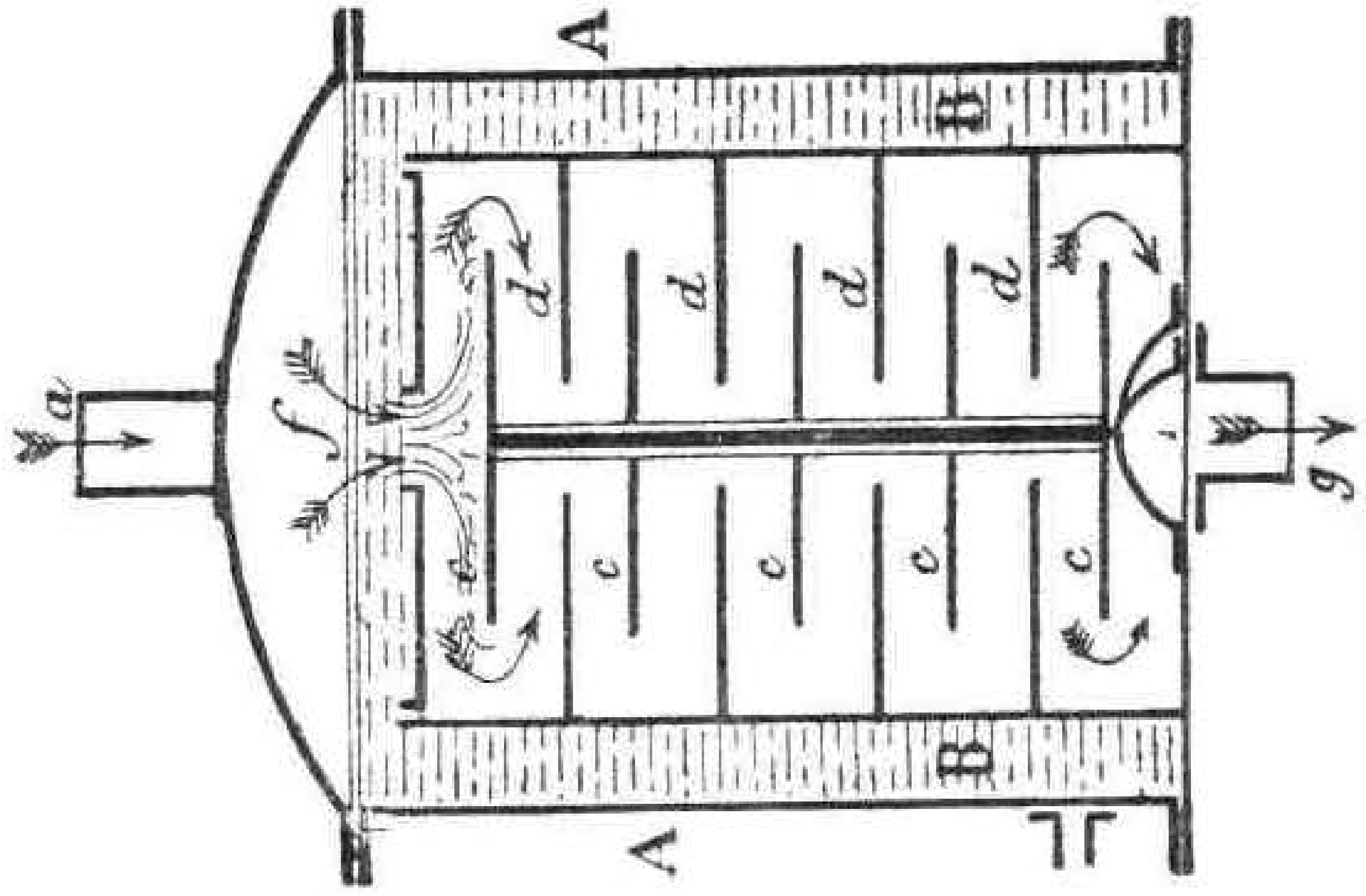


Fig. 7.

CATARACT CONDENSER. Fig. 8.

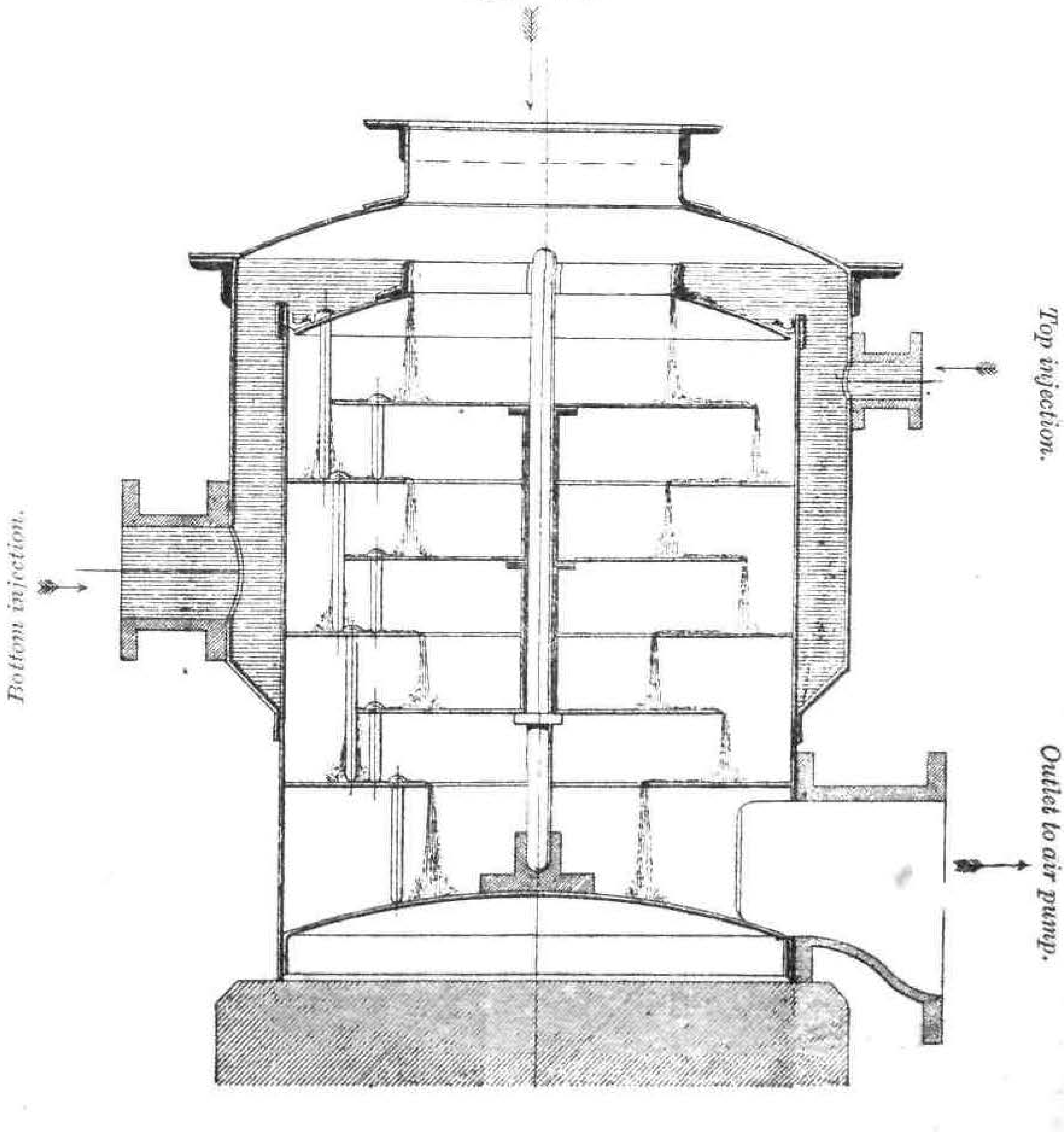


Fig. 7 is constructed as follows: An exterior cylindrical vessel AA, in which is placed a second cylindrical vessel BB; the cover of the vessel A, as well as the cover of the vessel B, are removable; on the outer vessel the inlet *a* is for the vapour to be condensed, and the inlet *b* for the injection water; in the inner vessel are ringed plates *d*, *d*, *d*, *d*, between these there are plates *c*, *c*, *c*, *c*, which are fitted into a rod provided with short lengths of tube, to keep them at equal distances apart, these all being removable, allows of the whole of the inner apparatus being easily taken out; the rings and plates must not be perforated, by this arrangement the whole of the water falls in a cataract from ring to plate and from plate to ring, giving the greatest possible course in common with the vapour, and presenting a very great surface for condensation. In the whole of this condenser there is neither rose, perforated plate, nor sieve, so that no obstruction can take place, and does not require opening during the whole of the working season, even if the water deposits any organic substance it will work equally well.

The vapour to be condensed enters at *a*, the condensation water at *b*, and rises in the annular space, and falls through the opening *f*, together with the vapour with which it is thoroughly mixed; it then falls, as described, in a thin stream, completely condensing the vapour to the outlet *g*, which leads to the air pump. If a wet air pump is used with this condenser and draws off the condensation water direct, the opening *f* must not be higher than 5 metres above the lowest water level of the source of supply. Besides the condenser with injection water there is also a surface condenser.

The surface condensers are only found here and there in sugar factories, and are made of coils placed vertically, and arranged in the same way as in the evaporation apparatus; according to requirements, 5 or 6 coils are used, over each coil is placed a gutter for supplying the water, which is allowed to flow through them in thin streams, and condenses the vapour, these are called Deronne's condensers, and are no longer in use with us. It is different with the tube condensers, also called calorisators, which are often used in sugar factories, as they maintain the heat for the purpose of making the vapour useful; strictly speaking, they are not condensing apparatus.

K.—THE CALORISATORS OR RE-HEATERS.

The vapour going off from a Triple Effet to the condenser is always of a sufficiently high temperature to serve as a heating medium, which is completely lost when it goes to the condenser. For a long time it has been thought to make use of this heat by placing between the condenser and the last vessel a calorisator or re-heater, also for a Quintuple Effet, as it is only rational that this otherwise lost heat should be utilised. The reason why in many factories this system of re-heating has been given up, is not through any fault of the system but of the arrangement.

The calorisator is for heating the diffusion juice by means of the vapour coming from the last vessel, but it seldom answers its purpose, and should be abandoned, and direct or exhaust steam used; even then it will imperfectly fulfil the object, for this reason: that when a liquid which is below boiling point has to be re-heated, it takes up heat with difficulty, and the transmission co-efficient of the heating power falls 60 to 70 per cent. of its value; the cause of this is that the liquid is nearly motionless as soon as it comes to boiling point, the transmission co-efficient immediately rises from 4 to 5, to 15 and 20, and higher; this has been fully explained when describing the evaporating apparatus in the first part of this essay. It is seldom that the makers of re-heaters take into account this circumstance.

The re-heaters in use up to the present are mostly vertical, of the form of Roberts' evaporating apparatus, the only difference is that in the re-heater the vapour circulates through the tubes, in Roberts' apparatus the diffusion juice. For a factory which works off 10,000 kilos of Beet per hour, giving 18,000 kilos of juice, equal to 18 cubic metres, the specific weight of which is generally 1·023; they have generally a heating surface of 100 square metres, the tubes are 50 m/m diam. inside × 1,200 m/m long, each having a heating surface of 0·188 square metres, will give $\frac{100}{0 \cdot 188} = 532$, equal to a total area of $0 \cdot 00195 \times 532 = 1 \cdot 037$ square metres, one tube having an area of 0·00195 square metres, the juice will flow through it at a velocity of $\frac{18}{1 \cdot 037 \times 3600} = 4 \cdot 8$ metres per second; by this slow move-

ment the juice is not only slowly heated, but an opportunity is allowed of sediment or scale forming on the tubes, which will in time reduce their capacity of transmission; in the diffusion calorisators having from 2 to 3 square metres of heating surface, notwithstanding that the same class of juice passes through them the tubes remain clean, but the velocity of the juice is 30 times quicker than through the large calorisators, which serve for heating the juice before going to the diffusion battery. On this ground opinions are divided as to the working capacity of the large calorisators. In some factories these work well, and without much sediment or scale forming on the tubes, whilst others give great trouble with this, and they can do nothing with them. In comparing these, it will be found that those that give the least trouble are fitted with long tubes, and few in number. Notwithstanding the diffusion water contains a large quantity of mineral ingredients, the other having many and short tubes.

A case came under my notice where a factory had a calorisator with 45 sq. metres of heating surface and worked without any trouble, two others with the same heating surface were placed beside it, to work simultaneously, and when worked gave all the troubles mentioned, as soon as they were arranged as a battery one working after the other there was no more trouble.

As a calorisator cannot well be constructed with tubes larger than 2 to 3 metres, they must be arranged the same as in the Wellner-Jellinck evaporating apparatus, by this arrangement the velocity of the steam can be maintained in the tubes, which are divided into groups, the total area of each group being equal to the area of the steam supply pipe, and arranging them so that the steam flows through them one after the other; the tubes of a calorisator can be arranged exactly the same, and will represent a Wellner-Jelinck evaporating apparatus, with the upper part above the heating chamber taken away and closed.

If the vapour enters the chest at the opposite end to that at which the juice enters the tubes, it will then be a counter current steam calorisator in which the full velocity of the diffusion juice is maintained; the tubes are accessible for cleaning and changing and work very well. The diameter of the tubes should be as small as possible, so as

to give a large contact surface with the vapour, they should, however, not be less than 35 m/m, so that in case of need they can be easily cleaned inside; when the vapour has passed through the calorisator, and given off the greater part of its heat, it then goes to the condenser.

(*L*) THE AIR-PUMP.

The air-pump is as important as the apparatus, even when it is in the best order, a badly designed air-pump can considerably reduce the working capacity of an evaporating plant; these are designed and constructed in many forms, the best known are the following :—

1. Horizontal double-acting bucket wet air-pump, the engines having spring pistons; these are mostly used in Austria.
2. Horizontal double-acting plunger air-pump, as wet air-pump, are most used in England.
3. Vertical double-acting dry-air pumps, most used in Germany.
4. Vertical single-acting wet air-pumps were formerly used in Austria, but are now abandoned.

It is not intended to describe these air-pumps in detail, as all of them are known to the reader.

They are all good, if they have no faults in design or construction, and suit local conditions, and the wishes of the manufacturers, &c., whichever is used. The air-pump in general will here only be treated, and its position in respect to the evaporating plant. The chief point, therefore, is to decide the right dimensions of it for any evaporation plant under consideration. It has to draw off the water necessary for the condensation, condensed vapour, and air contained in the condensation water, the air and gases, which are disengaged from the Beet juice boiling in the 1st, 2nd, and 3rd vessels of a Triple Effet, also the air which penetrates into the apparatus through the pores of the materials of which they are made.

Of these factors the following are known :—

The quantity of injection water is in round numbers 20 to 40 times the weight of the water evaporated in the 3 vessels. The air in the injection water, according to

Bunsen, is in the following proportions:—Water sets free at 0° C and 760 m/m level of barometer, volumes of air:—

0°	0·02471
5°	0·02179
10°	0·01953
15°	0·01795
20°	0·01704

The quantity of air and gases discharged from the boiling juice is unknown, also that which penetrates the apparatus through the pores of the metal; any direct calculation is therefore impossible, as they are only of problematical value.

A condensing engine requires for condensing the exhaust steam, about 28 times its weight in water, and the dimensions of the air-pumps are such that for each kilo of steam to be condensed per minute, the bucket has a space of 0·12 to 0·15 cubic metres to pass through, therefore a better vacuum is formed than in an evaporating apparatus. The air contained in the exhaust steam of a condensation engine goes into the boiler with the feed and injection water, this contains the same amount of air as the injection water for an evaporating apparatus, yet there is a sensibly better condensation. The exhaust steam from a condensing engine contains none of such gases as the vapour from boiling juice, it can therefore only be ascribed to these, notwithstanding the use of cold injection water, and the best condensers, so high a vacuum cannot be developed in the *evaporating apparatus as in a condensation engine*, even if the air-pump is of the above dimensions.

Our knowledge is therefore only proportional, and from practical experience it is absolutely necessary to raise the numbers of 0·12 or 0·15 cubic metres to 0·3, and not less than to 0·25 to obtain 600 m/m of vacuum, it is only under most favourable circumstances that a lower number than this can be used, which however, is not to be advised. This applies not only to the wet, but also to the dry air-pump, as the difference of space required by both is only about $\frac{1}{15}$ less in favour of the dry pump, being the smaller quantity of injection water it has to draw off; against this the dry air pump has a detrimental space which is not filled with water, longer pipes for the air and gases, both of which are fully equal to the $\frac{1}{15}$.

(*F*) THE ECONOMICAL USE OF STEAM BY VARIOUS METHODS OF EVAPORATION.

The engine, and the various methods of evaporation, will now be thoroughly criticised, not in separate paragraphs, but together, and in such order as may be required. In the first part of this essay the existing evaporating apparatus of the old system was criticised, and an apparatus of a new construction was recommended to take its place.

In this essay the theory of the evaporating apparatus has been developed, and the general effect of the multiple application of the steam in the evaporating plant, and arranged in tables. I pass on now to the practical work of the evaporating plant, and shall try to refute the ruling prejudices and false views of my various predecessors on evaporation, and lay before my readers various modes of operation in comparative statements. I shall, therefore, treat connectedly the economy of steam in the engine and boiler house in a separate section.

The false view which prevails in many sugar factories, that an economically working engine is not in place in a sugar factory, is founded on the use of the exhaust steam for the evaporation, and causing a permanent loss of fuel.

In the Austrian Journal of the Sugar Industry there is an essay by Director Polaczek, of Russia, which treats on this matter. I recommend the careful reading of it to everyone who would set himself right.

I shall only touch briefly upon this subject, and establish the incorrectness of this view by a special example.

The high pressure engine, at present used in our factories, working at a low pressure, and a piston speed of one metre, consumes nearly 45 kilos of steam per horse power per hour, showing a loss of steam by condensation equal to about 0·3 of the steam used. An economical working high pressure engine with expansion, and a piston speed of at least 2 metres, consumes at most 15 kilos of steam per horse power per hour, showing a loss of about 0·25.

A sugar factory which works 2,400 metric centals in 24 hours, or 10,000 kilos of Beet per hour, requires, as has already been shown, 150 horse power. If the above data is substituted in this example, it gives

(*a*) With an engine that does not work economically, $150 \times 45 = 6{,}750$ kilos of steam consumed per hour, and $24 \times 6{,}750 \times 0{\cdot}3 = 48{,}600$ kilos loss of steam in 24 hours.

(*b*) With an engine working economically,

$150 \times 15 = 2{,}250$ kilos of steam consumed per hour, and $24 \times 2{,}250 \times 0{\cdot}25 = 13{,}500$ kilos, loss of steam in 24 hours.

These are losses which could not take place if the steam was supplied direct to the heating chamber of the evaporating apparatus. By sixtuple evaporation, the loss in the 1st case would be

$\frac{48600}{6} = 8100$ kilos of coals in 24 hours, or 3·4% of the weight of Beet worked.

In the 2nd case $\frac{13500}{6} = 2250$ kilos of coals in 24 hours, or 0·9 % of the weight of Beet worked.

Difference and saving = 5850 kilos of coals in 24 hours, or 2·5 % of the weight of Beet worked.

It is seen from this example how advantageous it is to have an economical working engine, and to supply the steam required for evaporation direct to the heating surface of the apparatus.

If the above examples are more closely considered, it will be found that the largest factor in the calculation is the consumption of steam per horse power per hour. The loss of steam caused by the construction of the engine, which in the 1st example is 0·3, and in the 2nd 0·25, does not sensibly differ, but the difference between these is very great when this factor is multiplied by the consumption of steam; in other words, the higher the consumption of steam by the engine per horse power per hour, so much greater is the loss for the evaporating plant. Every factor which increases this consumption of steam causes an increased loss of steam.

If the back pressure be increased in the engine, the consumption of steam will be greater, and in consequence the loss of steam also increases for the evaporating plant, it is *therefore prejudicial to sensibly increase the pressure of* the exhaust steam, in order to reduce the heating surface in the apparatus. A greater source of the loss in steam for the evaporation is the many small engines, which up to the present have been used in sugar factories. It is

known to every engineer, that the smaller the engine, so much the more steam it requires per horse power; this difference can be very considerable as is known; it is therefore self evident that the driving power should be concentrated as much as possible, but on no account one central engine (small steam and exhaust pipes also cause a loss of heat.) If the local conditions are not suitable, or the factory in its arrangement not expressly constructed for it, it can easily happen that a central engine would do more harm than good; what is meant by a central engine is one that is in direct connection with the pumps, and gives the driving power for all belt and wheel transmissions, or to part of them. Whoever overlooks this can participate in double the amount of loss which he thought to be free from, by directly increased consumption of steam and irregular working, the consequence of which is not to be neglected. By reducing the steam consumption in the engine to a minimum, the evaporating apparatus will have to be supplied with direct steam, before this is decided on, it will first be seen if this is altogether necessary, and when it should be the case.

As already shown, a factory working 10,000 kilos of Beet per hour, giving 18,000 kilos of juice, has to evaporate 17,400 kilos of water, including the washing water to 50% Balling, this will now be evaporated to 60% Balling in the last vessel, which will give 18,000 kilos of water to be evaporated, the advantages of concentrating to this higher degree will be explained.

A 150 H.P. economical working engine gives per hour:

$150 \times 15 \times 0{\cdot}75 = 1687$ kilos of exhaust steam, which can be used in the apparatus.

With this steam, by quadruple evaporation, $1687 \times 3{\cdot}79 = 6393$ kilos of water can be evaporated.

There being 18,000 kilos of water to be evaporated, there will be $\frac{18{,}000 - 6{,}393}{3{\cdot}79} = 3{,}062$ kilos of direct steam to supply, to evaporate the juice to 60% Balling by quadruple evaporation. There will be in this case two classes of steam to supply into the apparatus, that is, low pressure exhaust and high pressure direct steam. As this latter cannot be supplied into the same chamber as the exhaust steam, a separate heating system is placed in the first vessel of the Multiple Effet.

The question now arises, What should be the pressure of the heating steam for the evaporating plant? This allows of a direct reply, as follows:—An economical expansion engine cannot work against a higher back pressure than ½ an atmosphere for reasons already stated, so that it will be advantageous to reduce it to ¼ of an atmosphere, and make the heating surface of the apparatus larger.

To have the greatest effect from the conversion of the latent heat in the steam for the evaporation, it should always remain at a low pressure. In a properly constructed evaporating apparatus, the condensed water from the heating system when it arrives in the closed water receiver, should have a temperature proportional to the steam pressure under which it was formed, and equal to that of the steam. Accordingly, the condensed water from high pressure steam will return more heat (which can in the first place be converted in the boiler) than that from low pressure steam; therefore, there will be less useful calorie than in first using the steam.

The following example will explain this:—

Steam pressure in atmospheres	1	2	3	4
Heat in calories	637	643·28	647·34	650·42
Heat of the condensed water in calories	100	120·60	133·91	144·00
Useful heat in calories ..	537	522·68	513·43	506·42

From which it is evident that by increasing the pressure of the heating steam the immediate conversion of the calorie is smaller. The condensed water returning to the boiler is proportionately hotter, the higher the pressure of the heating steam, in consequence of this the loss by cooling on its return course is greater on account of the greater difference of temperature.

This gives an idea as to the pressure to be applied in the apparatus, and should be taken into account conformably to local circumstances, resulting in the following; high pressure steam to drive the engine, and less back pressure, and to use low pressure for boiling.

The boiler for generating high pressure steam, for driving the engine, being independent of the others, is only advantageous when the engine is constructed to work with it; if this is not so, the advantages are illusory.

In the application of direct steam for boiling, the heating surface stands naturally in inverse proportion to the steam pressure of the heating steam. The greater the pressure the smaller the heating surface and the apparatus. In this case the pressure of the heating steam on the whole surface should be kept equal, and at full pressure; if this is not done, and the steam can expand in the heating space, the loss of heat will be correspondingly large. For example, if 1 kilo of steam at $3\frac{1}{2}$ atmospheres expands to $1\frac{1}{2}$ atmospheres, so will the pressure in the exhaust steam and water receivers, loosing about 8 heat units which cannot be regained; therefore, the saving is little by little, which becomes a considerable amount if the theory of heat is used serviceably, and what it teaches is applied conscientiously and methodically.

As to the multiple conversion of the heating steam in the evaporation, this has its full effect, when the concentration of the juice is carried as high as possible before going to the vacuum pan.

Two examples will make this clear, first evaporating to 35% Balling, the second to 60% Balling.

From 100 kilos of Beet, which gives 180 kilos of juice at 8% Balling, there should be a residue of 95% masse cuite, entering the vacuum pan at 35% Balling; it is concentrated until there is only 5% of water left in it; the same amount of juice should, in accord with the saving of fuel, be evaporated from 35% to 60% Balling, and then to the vacuum pan to be boiled to 95% masse cuite. The first example will be denoted by A, the second by B.

A. From 180 kilos of juice of 8% Balling there is $180 (1-8/35)=139$ kilos of water to be evaporated.

B. From 180 kilos of juice of 8% Balling there is $180 \cdot (1-8/60)=156$ kilos of water to be evaporated.

There is in example A $180-139=41$ kilos of thick juice, at 35% Balling.

There is in example B $180-156=24$ kilos of thick juice, at 60% Balling.

There is required for the evaporation of the thin juice—

(*a*) with Double Effet :—

By $A=139\times0{\cdot}51=70{\cdot}89$ kos. steam, or $\frac{70{\cdot}88}{6}=11{\cdot}81$ kos. coals.

,, $B=156\times0{\cdot}51=79{\cdot}56$,, ,, ,, $\frac{79{\cdot}56}{6}=13{\cdot}26$,, ,,

(*b*) with Triple Effet :—

By A $=139\times0{\cdot}35=48{\cdot}65$ kos. steam, or $\frac{48{\cdot}65}{6}=8{\cdot}11$ kos. coals.

„ B $=156\times0{\cdot}35=54{\cdot}60$ „ „ „ $\frac{54{\cdot}60}{6}=9{\cdot}10$ „ „

(*c*) with Quadruple Effet :—

By A $=139\times0{\cdot}26=36{\cdot}14$ kos. steam, or $\frac{36{\cdot}14}{6}=6{\cdot}02$ kos. coals

„ B $=156\times0{\cdot}26=40{\cdot}56$ „ „ „ $\frac{40{\cdot}56}{6}=6{\cdot}76$ „ „

(*d*) with Quintuple Effet :—

By A $=139\times0{\cdot}21=29{\cdot}19$ kos. steam, or $\frac{29{\cdot}19}{6}=4{\cdot}86$ kos. coals.

„ B $=156\times0{\cdot}21=32{\cdot}76$ „ „ „ $\frac{32{\cdot}76}{6}=5{\cdot}46$ „ „

For the evaporation of the thick juice to masse cuite of 95 % sugar, in all cases of A one with another, and in all cases of B one with another, remains the same.

By A 41 kilos of thick juice gives $= 41\left(1-\frac{35}{95}\right) = 26$ kilos of water to be evaporated, and

By B 24 kilos of thick juice give $=24\left(1-\frac{60}{95}\right)=8{\cdot}84$ kilos of water to be evaporated.

There is therefore required :—

A $=26\times1{\cdot}11=28{\cdot}8$ kilos of steam, or $\frac{28}{6}=4{\cdot}66$ kilos of coals.	For the vacuum pan.
B $=8{\cdot}8\times1{\cdot}11=9{\cdot}76$ „ „ „ $\frac{9{\cdot}76}{6}=1{\cdot}6$ „ „	

If the individual results are put together there is—

For A :—

(*a*) Double Effet $=11{\cdot}81$ kilos of coals + the vacuum pan $=4{\cdot}66$ kilos of coals; total $16{\cdot}47$ kilos of coals.

(*b*) Triple Effet $=8{\cdot}11$ kilos of coals + the vacuum pan $=4{\cdot}66$ kilos of coals; total, $12{\cdot}77$ kilos of coals.

(*c*) Quadruple Effet $=6{\cdot}02$ kilos of coals + the vacuum pan $=4{\cdot}66$ kilos of coals; total, $10{\cdot}68$ kilos of coals.

(*d*) Quintuple Effet $=4{\cdot}86$ kilos of coals + the vacuum pan $=4{\cdot}66$ kilos of coals; total $9{\cdot}52$ kilos of coals.

For B :—

(*a*) Double Effet $=13{\cdot}26$ kilos of coals + the vacuum pan $=1{\cdot}6$ kilos of coals; total, $14{\cdot}86$ kilos of coals.

(*b*) Triple Effet = 9·10 kilos of coals + the vaccuum pan = 1·6 kilos of coals; total, 10·70 kilos of coals.

(*c*) Quadruple Effet = 6·76 kilos of coals + the vacuum pan = 1·6 kilos of coals; total, 8·36 kilos of coals.

(*d*) Quintuple Effet = 5·46 kilos of coals + the vacuum pan = 1·6 kilos of coals; total, 7·06 kilos of coals.

And there is then A—B:

By *a* = 16·47—14·86, an effective saving of 1·61 kilos of coals, or per cent. By *b* = 12·77—10·70, an effective saving of 2·07 kilos of coals, or per cent. By *c* = 10·68—8·36, an effective saving of 2·32 kilos of coals, or per cent. By *d* = 9·52—7·06, an effective saving of 2·46 kilos of coals, or per cent.	Of the weight of Beet worked.

From this it will be seen that the juice should undergo a higher concentration before going to the vacuum pan.

How far the concentration should be carried is decided by the price of coals, and the heating surface of the apparatus.

As highly concentrated juices will not filter, a part of the heating surface of the last vessel has been divided off, and as explained, it is concentrated in one part up to 50 Balling, then filtered, and evaporated in the second part 60%, and even 70% before going into the Multiple Effet vacuum pan.

If it is wished to carry the saving of coal still further, the Double Effet vacuum pan can be heated from the first vessel, or with more effect from the second vessel of a Triple Effet. If the above example is taken as a guide, the consumption of coal, when it is possible, can be reduced for the vacuum pan from 1·60% to $\frac{8{\cdot}7 \times 0{\cdot}51}{6} = 0{\cdot}73\%$, relatively to $\frac{8{\cdot}7 \times 0{\cdot}36}{6} = 0{\cdot}50\%$, there should be taken into consideration that in consequence of this, to finish boiling, the vapour for the first and second vessels must be highly compressed to maintain the difference of temperature required for boiling in vacuum. This requires the pressure of the exhaust steam to be increased to more than one atmosphere, and in consequence of this, and under certain conditions, there is lost what has been gained.

If a part of the direct steam required for heating is compensated by the vapour of the evaporating vessel, there will naturally be a saving of steam in the multiple application of it. Vapour from the first vessel applied for heating gives a less saving of steam than vapour from the second or third vessels, as this is already a product of double or triple use of the steam. two explanations will be given of it; to show this clearly, a diagram is given with each calculation and explanation.

There is an extraction of 180% of juice from the weight of Beet, of which (see example, page 146) 174% of water is to be evaporated in a Triple Effet, to produce syrup.

For the diffusion, which should be heated with the vapour, requires according to the above	15·0 %	steam
For heating before the first carbonatation and during the first carbonatation, which should also be done by the vapour ..	22·8 %	„
For boiling in the vacuum pan 20 % of steam is required, of which however, only 10 % should be vapour, and the rest direct steam to finishing boiling, therefore	10·0 %	„

FIRST EXPLANATION.

There is to be heated :—

The diffusion from the second vessel.

The *carbonatation from the first vessel.*

The *vacuum pan from the first vessel.*

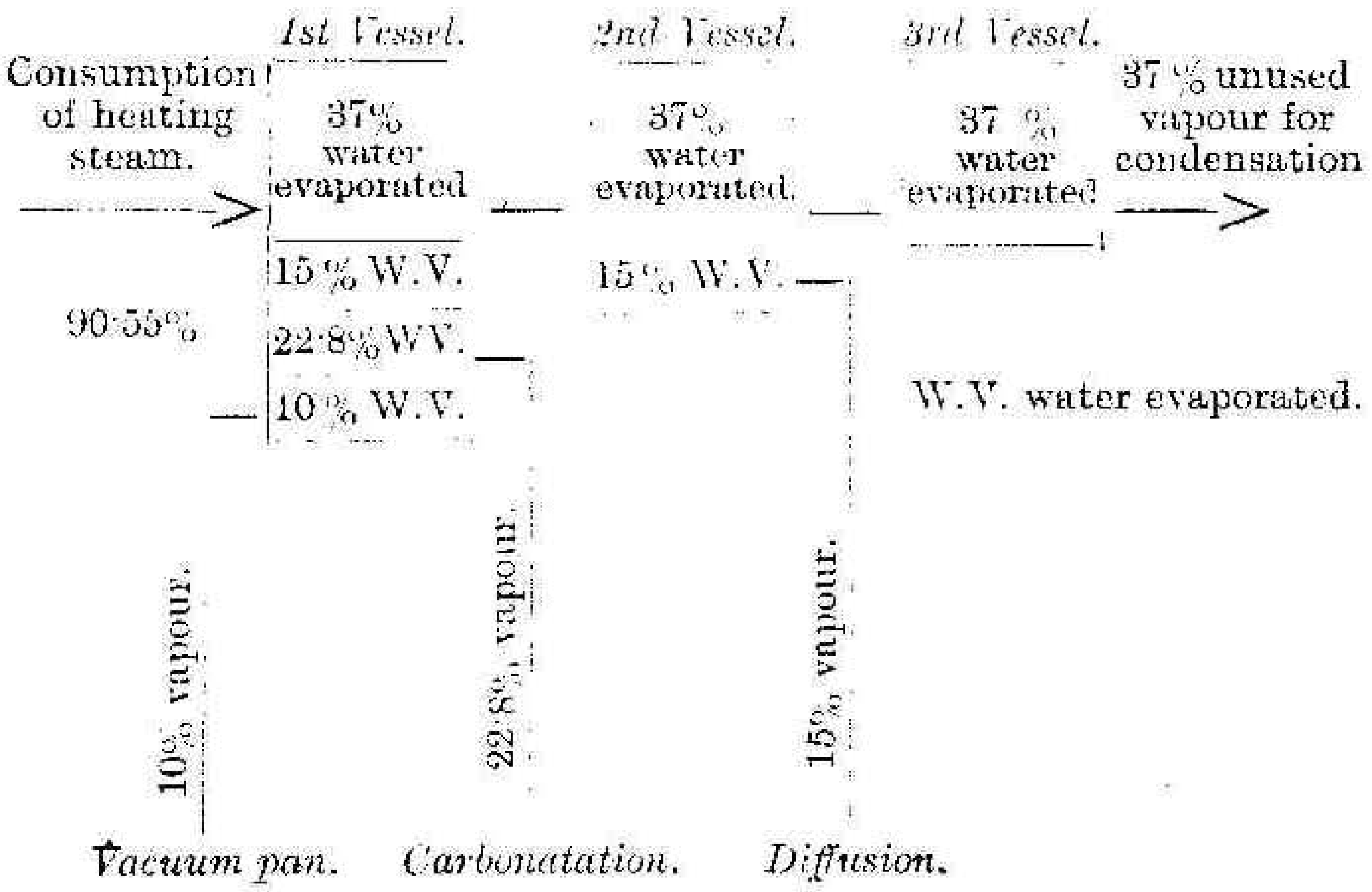
The steam required to evaporate the water from the juice, which forms the vapour for heating the Diffusion in the 1st vessel..15 } „ in the 2nd „ ..15 } =	30·0 %	„
For forming the vapour in the 1st vessel for the carbonatation	22·8 %	„
For forming the vapour for the vacuum pan in the 1st vessel	10·0 %	„
Total	62·8 %	steam.

There remains, therefore, for the clean Triple Effet to evaporate, 174—62·8=111·2% of water; so that there is in each vessel, after deducting the required evaporation for heating, 111·2÷3=37% water to be evaporated.

The total steam required for the evaporation if the juice is supplied at 75% C., is

30·0%	Double Effet=30·0×0·51=	15·30%	steam.
32·8%	Simple Effet=32·8×1·11=	36·40%	„
111·2%	Triple Effet=14·2×0·35=	38·85%	„
	Total - -	90·55%	„

DIAGRAM No. 1.



SECOND EXPLANATION.

There is heated the diffusion, which is divided as follows:—

The diffusion water heated from the 3rd vessel.
The diffusion juice heated from the 2nd „

The carbonatation is divided as follows:—

The juice before going to the carbonatation tanks is heated to 35° from the 3rd vessel, and heated to the highest required point from the 1st vessel.

The first or pre-vacuum is heated from the 2nd vessel.

The steam required to evaporate the water from the juice which forms the vapour for heating the diffusion juice, deducting 5% for heating it by the vapour from the 3rd vessel, there is—

For 1st vessel 10	} =	20·0 % steam.
For 2nd „ 10		
For forming in the 1st vessel the vapour for the carbonatation		12·8 % „
10% of steam is deducted for heating from the 3rd vessel, which costs nothing.		
For heating the pre-vacuum pan—		
From the 2nd vessel 10	} =	20·0 % „
From the 1st „ 10		
Total		52·8 % steam.

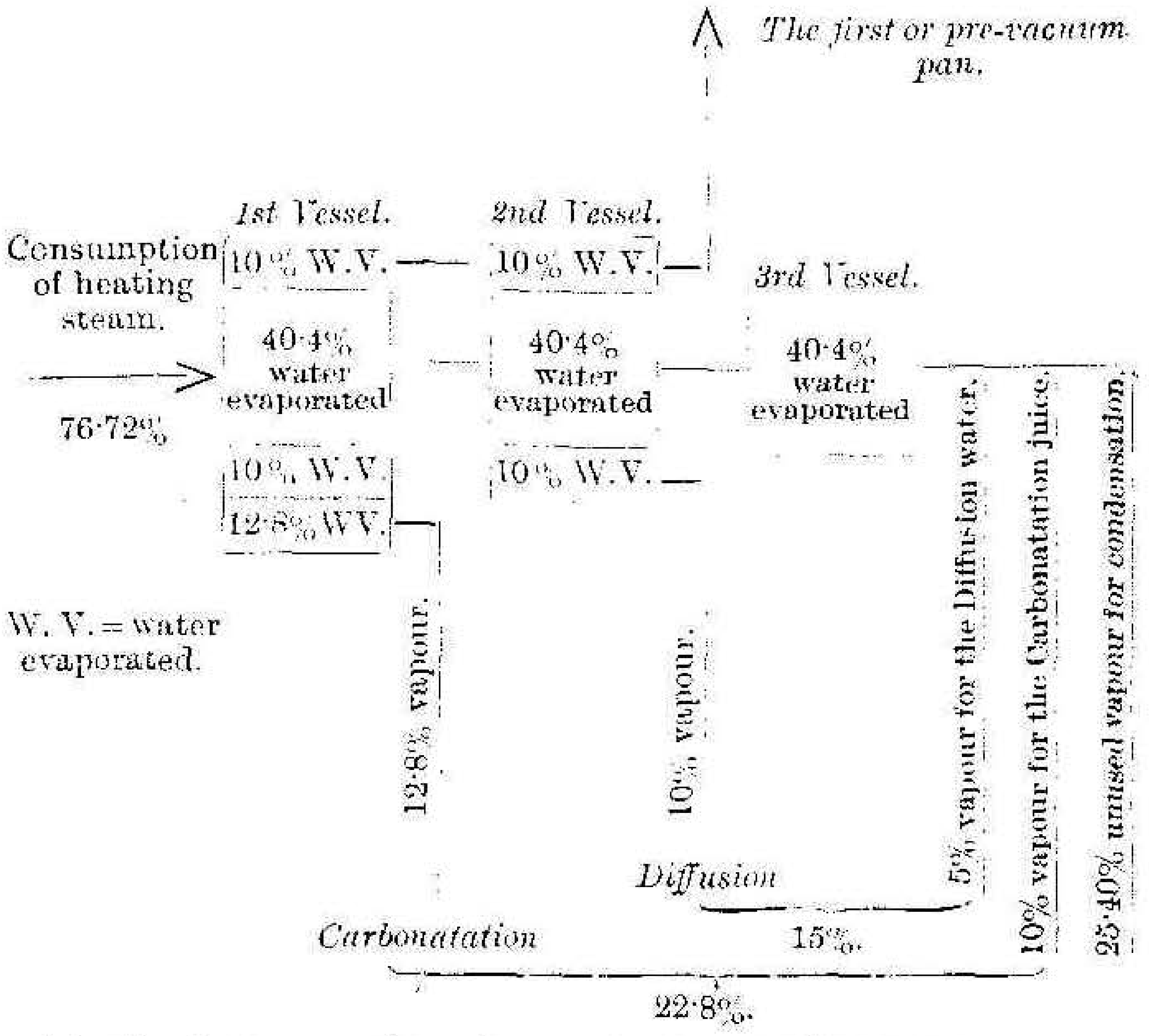
The clean Triple Effet has, therefore, to evaporate 174—52·8=121·2% of water.

There is in each vessel, after deducting the required evaporation for heating, 121·2 ÷ 3=40·4 % water to be evaporated.

The total evaporation required in steam if the juice is supplied at 75° Celsius.

20·0%	Double Effet	20·0 × 0·51=10·20 %	steam.
12·8%	Simple Effet	12·8 × 1·11=14·20 %	„
20·0%	Double Effet	20·0 × 0·51=10·20 %	„
121·2%	Triple Effet	121·2 × 0·35=42·12 %	„
	Total	76·72 %	steam.

DIAGRAM No. 2.



In the first case there is required. . 90·55 % steam
In the second case „ „ . . 76·72 % „

Difference in favour of the 2nd case 13·83 % steam saved on the weight of Beet.

From this it will be seen that it is more advantageous to use as far as possible the vapour of the last vessel, as it arises from a multiple application of the heating steam, which otherwise goes unused to the condenser.

Even if the difference of temperature in such a case be less, still this can be partially compensated by the heating surface, and every atom of heat which is made useful in this way is practically gained. It was formerly lost; the gain shows no further loss on either side, as the whole evaporating apparatus remains unaltered.

At all events, let the price of coal be decided at place and station, and compare it with the price of erecting an apparatus, engine, &c., which is required for the reconstruction of the evaporating plant.

It has been shown in the first part of this essay, that by using the lost vapour from the evaporation in a Quadruple Effet 87·4% feed water can be obtained, which by a sextuple evaporation would represent about 14% less coal, which is the case where applied in Middle Bohemia.

If the coal would allow of an 8 to 9 fold evaporation with hot feed water, then naturally the coal consumption can be reduced to 9% or even 8% of Beet giving 180% of juice. The calculation must decide whether the saving of the last percentage of coal is also a saving of money.

Before closing this subject there is one important subject to mention, that is the feed water for the boilers.

How much money have sugar makers spent uselessly on various means to prevent incrustation in boilers, by a mechanical or chemical process. If it had been any other branch of industry, where the exhaust steam was allowed *to escape into the air, or that it was condensed in the condenser* of the engine, it would be natural that a means for preventing the incrustations should be adopted, as fresh water would have to be used for feeding the boilers. But in sugar factories, where there is so much fine pure water free from boiler scale—in other words, distilled water—in such a quantity, that under certain circumstances it cannot all be used; to use cleaning apparatus for boilers would be incomprehensible, if it did not lay in the nature of the thing.

The simpler the process is, the nearer lays the simple truth, so much the further off is it looked for, and with difficulty accepted. This lies in human nature and is found in all branches of industry. I cannot leave unmentioned that the fault also lies in this, that certain men maintained these points, until one or other revolting spirit opposed these party traditions. I refer only to the Caramel and Sulphur ghosts of the earlier years, and Ammonia of the present.

Because it is notorious that ammonia destroys the copper tubes, the fear of it is so great that most sugar makers still hesitate about feeding their boilers with ammonical water, and yet this does absolutely no harm to the boilers, which is easily proved; he is himself afraid of the experiment, at the same time he can easily obtain information from those of his colleagues who have used it for a year; but even those anxious hearts who will not

risk introducing ammonical water into their boilers, will still find as much hot condensed water in their factories as their boilers can use, without having recourse to a drop of fresh water to assist it, by suppressing all steam scumming, boiling, and heating, except by heated surfaces, and taking off the condensed water by means of self acting closed water receivers, separating the condensed water, rich in ammonia which cannot be used for the boiler from that which can be used, is the secret for obtaining more distilled water than the boilers can consume. When it is considered that a factory with a properly arranged evaporating plant will generate 200 % of vapour, 50 % of which is useless on account of the ammonia it contains, (?) 50 % goes to the condenser, leaving a balance of 100 %, being the greatest quantity of condensed water required for the boiler. There is also returned from the serpentines and other heating arrangements, at least 90 % of the required feed water, which was supplied as direct steam, so that this gives in all 190 % of condensed water, which represents the best boiler feed water, with an average temperature of 100° C., that this is correct admits of being easily calculated. It has been assumed in practice, that 100 kilos of Beet gives 180 kilos of juice from which there is to be evaporated 175 % of the weight of Beet, in water, before it becomes masse cuite, to this there must be added 20 to 30 % of the weight of Beet, of diverse washing water, therefore the total comes to fully 200 %.

(*G*) THE BOILER & ITS RELATION TO THE EVAPORATING PLANT.

If it is the desire to save fuel in a sugar factory, the the first thing to do to attain this object is the proper reconstruction of the evaporating plant, and in the second place the reconstruction of the boiler house. First to be considered is the saving of steam, and then the economical production of it.

Many boilers could in their present condition produce steam economically if they had not been forced ; in consequence of the evaporating plant not being in order, a large quantity of steam was required for evaporating the juice. It is therefore requisite, above everything, to carry out to

its fullest extent the multiple application of the steam in the evaporating plant, *then on the basis of the consumption* of steam, the necessary alterations can be made in the boiler house.

To what extent we can go with the evaporating plant depends on the price of fuel and the cost of the alterations.

But in any case the increase of the heating surface in the evaporating plant gives a better result than the increase of the heating surface in the boiler-house, as we shall see later; an increase in the evaporating apparatus assists the boiler, and is indirectly an increase of the heating surface of the boiler itself.

A good arrangement of the evaporating apparatus signifies a saving of steam, hence, a quick return of the *capital expended*, whilst *an increase of the heating surface* in the boiler-house only gives an economical generation of steam, and the *capital expended is only returned in a long* series of years.

If it is therefore desired to reconstruct the evaporating plant, it is necessary, in the first place, not only to know how much steam is generally consumed per metrical cental of Beet, but also how much there will be consumed in each separate apparatus of the manipulation. If this is settled, then it is not difficult to decide where a saving can be made. Therefore, care must be taken that *the separate parts are not supplied with unnecessary* direct steam, but where posssible with exhaust steam, or such steam as otherwise leaves the factory unused. The combinations in this arrangement are so manifold, that no fixed rule can be given for it; the local circumstances of each factory to be reconstructed must be closely considered.

In the course of these notes, tables have been given from which is *perceived that* by *the proper* construction of an evaporating plant the eventual consumption of steam *can be decided at once*, viz. :—132, 103, 87, and even 79 kilos per metrical cental of Beet worked, and 180% extraction of juice.

This would correspond to a consumption of steam relatively 73, 57, 48, and 43 kilos of steam per hectolitre of juice worked.

From this it will be seen that a boiler house can be too small for a steam consumption of 73 kilos of steam

per hectolitre of juice, at the same time it is large enough if the steam consumption be reduced to 48 or 43 kilos per *hectolitre of juice; a simple reduction of the area of the* firebars will in such a case be sufficient, whilst on the other hand an increase of the boiler power by the most complicated and expensive system will often avail nothing.

It may now be asked, what should be the boiler capacity in proportion to the evaporating plant? To which may be replied—

The consumption of steam per 100 kilos of Beet should never exceed 100 kilos on a juice extraction of 180%, and the boiler should be large enough to produce this quantity of steam. A Bouilleur boiler, with expensive coal, should never exceed 15 to 16 kilos of steam per sq. metre heating surface, if the coal be very cheap 20 kilos per sq. metre and per hour can be generated.

A Cornish boiler fired internally, notwithstanding the price of coal, should never be forced higher than a generative power of 12 to 14 kilos of steam per sq. metre and per hour, all tube boilers and boilers of the tubular type should never generate more than 9 to 11 kilos of steam per sq. metre per hour. The proportion of the fire grate surface, 1/15 to 1/25 must not be used, but an endeavour made to obtain a proportion of 1/40 to 1/80, according to the type of boiler.

If it is wished to retain this proportion, it can be calculated that with a Bouilleur boiler 65% of the heat units contained in the coal will be given off if the setting or building is good.

In Cornish boilers 72% of the heat units contained in *the coal are given off, and combined with tubular or other* boilers, with a very small proportional fire-grate surface, give off 78 to 80% of the heat units; the last, however, is only in exceptional cases, and the conversion of 90% of the heat units of coal only occurs in experiments; in practice, so high a percentage is not obtained. Cheap fuel always allows of a cheap and simple boiler, expensive fuel a more complicated and expensive one.

For a sugar factory a type of boiler is always to be chosen which has a large water capacity, so as always to have a provision of heat for the unequal consumption of steam in the factory, and not the large steam space.

Here will be given a practical example to illustrate more clearly what has been said above :—

Suppose the evaporating plant of a factory in connection with a boiler-house has to be reconstructed to work up 2,400 metrical centals of Beet in 24 hours, the boiler-house consisting of 4 Bouilleur boilers, each having 75 square metres heating surface, and 2 Fairbairn boilers, each of 90 square metres heating surface. The factory works with Double Effet, but is otherwise economical in consumption of steam, which is equal to 150% of the weight of Beet.

As 10,000 kilos of Beet are worked per hour, the boiler-house will have to supply $\frac{10,000 \times 150}{100} = 15,000$ kilos of steam per hour.

The total heating surface of the boilers is :—

$4 \times 75 = 300$ in Bouilleur boilers.
$2 \times 90 = 180$ in Fairbairn boilers.

Total 480 square metres.

One sq. metre of heating surface has, therefore, to produce per hour $\frac{15,000}{480} = 31 \cdot 2$ kilos of steam.

This quantity is so great that it is impossible to produce it economically.

Here the *importance* of the boiler system is *not* taken into consideration, but doing so, the calculation will show as follows :—

$4 \times 75 = 300$ sq. metres Bouilleur surface, equivalent to -	- 600 sq. m. Fairbairn.
$2 \times 90 = 180$ sq. metres Fairbairn surface is equivalent to	- 180 ,, ,,
Gives -	780 ,, ,,

Therefore, the production of steam is $\frac{15,000}{780} = 19$ *kilos* per sq. metre per hour by the Fairbairn boilers, and 31·2 kilos by the Bouilleur boilers, both enormous values, which have often come before me in practice.

The boiler-house capacity is in this case plainly about one half too small, and must be made at least twice the size to produce economical steam.

Suppose the evaporating plant is reconstructed according to Table II., part C. (see page 154), with a Quadruple Effet, and the heating improvements introduced therein mentioned, the consumption of steam is reduced to 87·4% of the weight of Beet, requiring 8,740 kilos of steam per hour, so that the same boilers would have to produce $\frac{8,740}{780} = 11{\cdot}2$ kilos of steam per square metre, per hour, as Fairbairn boilers, and $11{\cdot}2 \times 2 = 22{\cdot}4$ kilos as Bouilleur boilers. If coal be cheap, the boiler power is sufficient to work off the quantity of Beet, the fire-grate surface will have to be made smaller in proportion, as less coal will be used; if the coals are expensive, the heating surface of the boilers must be increased to an economical quotient of steam generation. Taking 9 kilos of steam for the Fairbairn, and 16 kilos for the Bouilleur boilers, the calculation stands as follows :—

EXISTING BOILERS.

Bouilleur	$4 \times 75 \times 16 =$	4800	kos. of steam	produced	per	hour.
Fairbairn	$2 \times 90 \times 9 =$	1620	,,	,,	,,	,,
Total	..	6420	,,	,,	,,	,,

There is required 8740 kilos of steam per hour, therefore 8740—6420=2320 kilos of steam to be provided for by an increase of boiler capacity. How should this increase be made? Should new boilers be added, or the Bouilleur boilers altered into tubular boilers, so as to increase the heating surface? This will certainly raise their economical working, in quantitative proportion, but be less productive.

If instead of 16 kilos of steam per square metre, per hour, 10 kilos is taken, it would not increase the steam production of the boilers, as the heating surface cannot be increased, therefore new boilers must be provided, which should be of a type to work with the greatest economy, with expensive fuel, and that will give one kilo of steam at the least cost of fuel.

These calculations depend on the cost of fuel, the new boilers, and the price of money.

To the Bouilleur boilers there would have to be added $\frac{2320}{16}=145$ square metres, or two boilers each, having 75 square metres heating surface, or to the Fairbairn boilers $\frac{2320}{9}=235$ square metres, or two of about 110 sq metres.

Whether we add two Fairbairn or two Bouilleur boilers, the cost of producing the steam will decide. In the present case we should probably be in favour of the Fairbairn boilers or some other system of equal value. But with very cheap coals it would be decided to take two Bouilleur boilers. In any case a calculation of this kind should be taken into account.

Before I leave this subject permit me to add a few hints, *not for the engineer*, who will find *nothing new* therein, but for the practical sugar maker that he may make himself acquainted on these points with the principles of the proper working of the boilers and the management of them.

The colours of the flame give us indication of the temperature of the burning materials.

The following table is made from M. Pouillet's experiments :—

Dark red corresponds to - - -	700°	temperature.
Cherry " " " - - -	900°	"
Dark orange " " - - -	1100°	"
White glow " " - - -	1300°	"
Highest white glow dazzling to -	1500°	"

The most complete combustion corresponds to the highest degree of temperature.

The *products of combustion which cool before they* reach the highest degree of combustion form into smoke.

The smoke therefore consists of unburnt gases, cooled products of the gases, carbon in the form of soot, and surplus atmospheric air.

For the best possible combustion it is requisite—

1. To reduce the quantity of fuel as much as possible.
2. To bring the small pieces of fuel into contact with the air, over the whole surface.
3. To regulate the introduction of the air so that there is no deficiency and no surplus of it.

4. To introduce these elements into the furnace in such a condition that the requisite temperature for the best combustion is not altered.

Furnaces which are so arranged that the gases developing, at once reach that part of the furnace where there is the greatest heat. Vertical furnaces are to be preferred.

The elements to be burned in any fuel are carbon and hydrogen.

Six parts in weight of carbon require 16 parts in weight of oxygen to produce 22 parts in weight of carbonic acid.

One part in weight of hydrogen with 8 parts in weight of oxygen, burns in water.

One part in weight of air contains 0·77 part in weight of nitrogen and 0·23 part in weight of oxygen, or 1 volume of air contains 0·79 volume of nitrogen and 0·21 of oxygen.

By perfect combustion 8080 heat units are developed from 1 kilogram of carbon.

With these data it is possible to calculate the supply of air requisite for a certain fuel, if its elementary composition be known.

To burn 1 kilo of carbon, about 9 cubic metres of atmospheric air are required.

For the combustion of 1 kilogram of oxygen, 24 cubic metres are required.

To burn 1 kilo of coal requires theoretically 9 cubic metres of air, which will be denoted by 1. To arrive at a complete combustion, more air than the theoretic amount is required. If too much air is introduced, there will be a greater loss of heat than with a more sparing supply. The average proportional number for the supply of air should be for the different species of fuel between 1·2 and 1·5 of the theoretical amount, therefore, between 10 and 15 cubic metres per kilo of coals burnt. An example will make it perceptible how the loss of heat increases with the increased supply of air. Let it be assumed that 1 kilo of coal is burnt in 9 cubic metres of air. There is formed by complete combustion :—

3·38 K*g* carbonic acid
9·25 K*g* nitrogen
0·40 K*g* water

On the assumption that 1 kilo of coal contains 0·92 carbonic acid, 0·04 oxygen, and 0·04 water.

In round numbers, taking 0·25 as the specific heat for the nitrogen and carbonic acid, and the specific heat of the steam at 0·50, it will give a loss of heat by the smoke *and gases, if they are at* 300° C, viz. :—

$300 \, [(3{\cdot}38 + 9{\cdot}25) \, 0{\cdot}25 + (0{\cdot}40 \times 0{\cdot}50)] - 300 \times 3{\cdot}36 = 1008$ heat units: that is, nearly $\frac{1}{8}$ of the whole heat developed in the furnace.

If double the volume of air had been supplied there would be 12 kilos more air to heat, and, therefore, about $300° \times 12 \times 0{\cdot}25 = 900$ heat units more lost by going up the chimney, making a total of $1008 + 900 = 1908$ heat units, or nearly $\frac{1}{4}$ of the whole heat developed.

Whoever wishes to make a further study on the *pernicious influence of an excessive supply of air,* I would recommend to them specially the essay "Limiting the introduction of air, the simplest means of raising the heating effect of boiler firing, by Dr. Moritz Niese, Engineer and Teacher in the Technological Institute." This essay is *contained in* No. 22, 23 and 24, Vol. 8 *of* Neuen Zietschrtft für Rübenzuckerindustrie, edited by Dr. Scheibler.

The temperature of a furnace can be calculated by the following formula :—

$$t = \frac{W}{(ks + k_1 s_3 + k_2 s_2 \ldots .)}$$

W is the number of heat units required which the fuel contains.
k, k_1 k_2 the weight of the respective products of combustion.
s_1 s_2 s_3 the specific heat.
t the temperature developed.

We find by means of this formula, the following temperatures which arise from the combustion of the following bodies :—

Carbon burnt in atmospheric air, by supplying the simple theoretical volumes, gives - - 2700° C.

Hydrogen burnt in atmospheric air by supplying the simple theoretical volumes, gives - - 2600° C.

Carbonic gas burnt in atmospheric air by supplying the simple theoretical volumes, gives - - 3000° C.

In practice these figures, for reasons easily understood, are not attained.

The height of the layer of the fuel to be burnt in the furnace should neither be too thick nor too thin, a thin layer allows the admission of too much air, a thick layer the contrary.

The thickness of the layers are generally, viz. :—

For close burning coal	- 0·12 to 0·15	m/m.
„ caking coal -	- 0·15 „ 0·20	„
„ coke - -	- 0·20 „ 0·25	„
„ turf and wood -	- 0·25 „ 0·30	„

These figures, however, are only to be taken in a general way, as each kind of fuel should be analyzed at place and station, and then fix from analysis of the products of combustion, the thickness of the layer for each kind, and the respective furnace. The area of the fire grate surface is ruled by the quantity of coal to be burnt, it therefore varies. One square metre of grate surface can burn 50 kilos of coal per hour, but with an excessive or forced draught 200 kilos. Experience has shown, that in both these cases the product of combustion contains too much carbonic acid gas, so that a mean of these figures should be taken.

We can calculate that 1 square metre grate surface can burn with advantage—

80 to 100	kilos of	coals
150 to 200	„	wood or turf, and
120 to 140	„	coke.

The grate surface should never be more than 1 metre broad × 2 metres long, and one boiler should never have more than 2 square metres.

The height of the boiler from the grate bars varies, according to the quality of the fuel:—

0·35 to 0·40	metres	for coals
0·50 to 0·60	„	for wood, turf, etc.

Boilers which are fired internally have always a lower initial temperature than those fired underneath; this prevents the sudden expressive distillation of the fresh coal, at the same time it has the disadvantage that the gases formed, which have not reached the highest degree of oxidisation, can cool so far that their complete combustion is stopped. On this account they are better adapted for burning close coal.

In a boiler internally fired there is a greater advantage from the radiation of the heat than with external firing.

If a boiler that is fired internally is provided with a so called combustion chamber, it promotes the easy mixing of the developed gases, and gives space and opportunity for combustion. before they can cool on the sides of the boiler. Tube boilers with internal firing must absolutely have combustion chambers, so that the gases are not immediately cooled when they enter the tubes.

The furnace bars should, in all arrangements of furnaces have a slope to the back of 1/10 in their length.

A smoke consuming apparatus is only to be applied to the boiler where sanitary considerations require it, and generally costs fuel, *smoking chimneys are no proof of the* use of bad fuel, or cool chimney gases a proof of the use of good fuel. The chemical analysis in connection with practical observation is here the one and only means of coming to a conclusion. With this oportunity I again recommend the above essay of Dr. Niese, which affords a very elaborate survey of this subject.

The gas analysis can be made with the Arzab apparatus as altered by Professor Schwackhöfer for the analysis of gases, and the application of it for calculating the effective power of the boiler fire arrangement, is to be read in Professer Schwackhöfer's Technologie, Vienna, 1883.

The draught, irrespective of the weight of the stream of gas which the furnace delivers per second, is calculated according to the formula—

$$Z = Fd\sqrt{2g\,Ha\frac{t^1 - t}{(1 + a\,t^1)\,(1 + a\,t)^2}}$$

Z = the draught or weight of the stream of gas per second.
F = cross section of the furnace.
d = density of the stream of gas.
H = height of the furnace.
a = the expansion co-efficient of the gas.
t^1 = the temperature in the chimney.
t = the temperature of the outer air.

From this formula it is evident that :—

The draught is directly proportional to the cross section of the chimney.

The *greater the cross section* so much the *greater is* the draught.

By an increasing height the draught increases only in proportion to the square root, and consequently less.

The draught increases quickly with the temperature of the combustion gases until it reaches 200° C, from 200° to 400° the draught is nearly the same, at 300° the maximum is attained, above this it decreases.

The above formula does not permit of a correct calculation for the dimensions of a chimney, the local conditions must decide this, it is preferable to calculate the dimensions in a practical manner, that is, to decide as a basis the amount of coal to be burnt, and begin with the dimensions of the grate surface.

For example, for 1,000 kilograms of coals burnt per hour, with 3 square metres cross section the chimney is required to be 10 metres high.

For 1,000 kilos of coals burnt per hour, with 2·5 square metres cross section, the chimney is required to be 20 metres high.

For 1,000 kilos of coals burnt per hour, with 2 square metres cross section, the chimney is required to be 30 metres high, and so on.

Taking the fire-grate surface as a basis, there is—

For 10 m. high $\frac{1}{3}$ of the whole fire grate surface = the cross section.
" 20 " $\frac{7}{24}$ " " " = " "
" 30 " $\frac{1}{4}$ " " " = " "
&c., &c.

As a high chimney is always costly, and is only useful in proportion to the square root of its height, this should always be taken into consideration, and rather make the cross section larger, and the chimney not so high, if the situation of the factory will admit of it. Low lying and high surroundings require a high chimney. Each boiler is provided with a separate damper; there is also a damper in the main flue to the chimney to regulate the draught. Whether the chimney should be of iron or brick must be decided by local conditions. With us the last is preferred, whilst on the other hand, where labour and building materials are expensive, or labour difficult to procure, iron chimneys are preferred, the draught is in both cases the same. The iron chimney will, of course, not last so long as one built of brick.

The flues should be vaulted and made double to prevent cooling, and sufficiently large that a man can pass through conveniently in case of need.

Round chimneys with like dimensions and like cost of material are more stable than those built square or octagonal, and give less resistance to the wind.

The steam pressure in the boiler is to be measured by the pressure of a column of mercury of 0·76 metre height, having a cross section of one square centimetre, and termed one atmosphere, the temperature of the steam is the same as the temperature of the water from which it arises, without the presence of water, steam acts to heat, the same as any other gas.

Motionless water, from which the air is taken away, can be heated to a temperature of 105 or 110° C, without boiling, the slightest movement is sufficient to cause the formation of a mass of steam and a boiler explosion. Red hot plates bring about the so-called spheroidal condition of water, which also causes boiler explosions.

The amount C of the heat, expressed in calories, which is required to convert one kilogram of water at a temperature of 0° C into steam of *t* temperature, can be calculated by the following formula :—

$$C = 606{\cdot}5 \times 0{\cdot}305\ t.$$

This is Regnault's formula.

The *transmission* of heat by the boiler surface, irrespective of its steam production, is less in proportion to the distance it is from the furnace, therefore an increase of the heating surface by an addition to the end of the boiler, which is the furthest from the furnace, is irrational and costly.

To convert 1 kilo of water into steam of 6 atmospheres, there is required—

$$C = 606{\cdot}5 \times 0{\cdot}305 \times 159^\circ = 655 \text{ W E, heat units.}$$

In consequence of which, 1 kilo of good coal which contains 8,000 W E heat units will convert $\frac{8000}{655} = 12{\cdot}2$ kilos of water, from 0° into steam of 159° C ; most boilers give 40 to 75% of these figures, according to their construction. As already stated, the boilers in a sugar factory should only be fed with hot condensed water, which is nearly chemically pure, feeding by means of an injector can only be taken into consideration as a feed arrangement in case of need or accident. The safest is by a feed pump, delivering at its slowest speed three to four times the quantity of water

required by the boiler. The direct return of the condensed water from the steam coils into the boiler was general in sugar factories, when they boiled the juice in Hallet's steam pans, which were made to stand the full boiler pressure in the coils, and to return the condensed water quickly into the boiler. After being more extensively used, it has to a great extent been given up. When the boiler is fed direct by the return water from the boiling apparatus it must stand higher than the boiler, say about 2 to 2·5 metres, according to the size of the steam coil and the return pipe, and the boilers for the engines should be independent of those for the boiling apparatus, the first should be fed by the feed pump, and the latter by the return water, as described above.

The former work at a pressure from 5 to 6 atmospheres, and the latter at the highest 2½.

The different fuels require a different type of boiler. Coal giving a long flame, or wood require the boilers to be externally fired, and provided with bridges to permit of the complete burning of the gases developed before they cool, so as to produce a higher initial temperature in the furnace. For coal which is close burning, and does not give a large flame, boilers fired internally are recommended. Half-flame coal require boilers fired internally, and a combustion chamber, so that the gases can be burnt before they are cooled.

Boiler explosions are caused by the following :—

1. Faults in the construction or materials.
2. Want of water, so that it falls below the level of the fire grate.
3. Higher pressure than there should be, caused by faulty steam gauges, and the valves not acting.
4. Drawing off steam after standing some time.
5. Sudden and strong withdrawal of steam.
6. Fat in the feed water, which forms on the plates and prevents the contact of the water.
7. Feed water containing dissolved mineral elements, causing incrustation, by which the plates become red hot.
8. Leaky rivets and cracks in the plates, causing oxidation.
9. Condensed steam from the combustion gases which fall on to the cold places of the boilers that have long flues and corrode the plates.

10. Partial incrustation of the feed-water pipes.
11. Leaks which allow so much steam to escape that it is unbreathable in the boiler house in consequence of which the firemen leave it.

The steam pipe from the boilers to the factory should not be too large in diameter, to avoid an unnecessary surface which would cause a loss by condensation. For ordinary short pipes and low pressure the steam should have a velocity of 15 to 20 metres per second; with a pressure from 5 to 6 atmospheres and higher, 40 metres. For very long pipes it is always necessary that the pressure in the boiler should be about one atmosphere higher than that required for driving the engine, for the steam stop valve and pipes from the boiler to the main steam pipe a velocity of 20 metres per second can always be taken as a basis, from the steam pipe to the boiling apparatus 40 metres as a basis for the highest consumption of steam. Steam-engines working with a cylinder capacity of 0·80 require 20 metres velocity, and the same for a smaller capacity, and high expansion, and full capacity.

The steam pipes are made of copper, cast and wrought iron, and for the vapours containing ammonia, copper is to be preferred up to a diameter of 100 m/m, above this they can be made of cast iron, which is cheaper.

The boiler feed water pipes should never be copper, as they are destroyed by the multiple conversion of the steam containing ammonia. The brass valve box of the feed pump is frequently destroyed in the same way, so that it is better to renew it every year than to feed the boilers with cold water containing deposit.

Each square metre of steam pipe, if not well protected, condenses $1\frac{1}{4}$ to $1\frac{1}{2}$ kilos of steam per hour. Therefore, it is necessary to make these pipes as short as possible, and to protect them with a non-conducting composition, also to place the engine in a central position, and to work it as economically as possible. The last especially, as the loss by condensation from a bad working engine is very great, and directly affects the evaporating plant.

The diameter of the boiler feed pipes should be half as large as the diameter of the boiler steam pipe.

To one who wishes to be further informed, I can recommend as a short introduction, "Traité Pratique des Chaudieres à vapeur employées dans les manufactures,

&c., par J. Denfer." The connection and contents of the above data are, with free manipulation, taken partly from the above work.

I here hope that I have treated as exhaustively on the boiler-house as the limited space and the object of this essay permits. I now come to the conclusion.

H.—COMPARATIVE VIEW OF VARIOUS SYSTEMS OF MULTIPLE EVAPORATION.

Annexed the reader will find three plates, which explain three different arrangements of evaporating plant by drawings and explanations.

Plate 6. For factories with cheap coal. Simple Triple Effet, for evaporating the juice to 50 or 55% Balling, and boiling the same by Simple Effet vacuum pan.

Heating the diffusion juice, which goes to the carbonatation by Quadruple Effet, by means of the lost vapour from the Triple Effet in a counter stream calorisator, system Wellner-Jelinek.

Plate 7. Arrangement for using expensive coal. Evaporating the juice by Triple Effet, filtering it, then boiling the syrup in separate Double Effet, mixing with the thin juice and passing to the second vessel of the Triple Effet. The after products are boiled in the same Double Effet, and finished to 70% in a Wellner-Jelinek vacuum pan by direct and exhaust steam Simple Effet.

Plate 8. For a new arrangement with expensive coal. Triple Effet, which is heated by the exhaust steam of an economically working steam-engine, which exhausts at a pressure lower than the atmosphere, and mixes with the steam of a Simple Effet, which is heated with direct steam, and forms with the Triple Effet a Quadruple Effet.

The low pressure exhaust steam is used as heating steam for the Triple Effet, but the direct steam is applied to the Quadruple Effet. Heating the juice for the carbonatation by Quintiple Effet, the III. and IV. vessels to be taken together, and divided into two parts, the one-half boils the juice to 45% Balling, it then passes to the filters, the other half, which serves as a pre-vacuum pan, the boiling being finished as Quadruple Effet.

This class of combination is possible to any extent, but I confine myself to these three principles.

The following Tables will be useful to sugar engineers, who wish to study more fully the matter of heat in the manufacture of sugar :—

1.—TABLE FOR SATURATED STEAM, ACCORDING TO ZEUNER.*

Pressure in		Temp. in degrees Celsius.	Heat of liquid. (q)	Internal evaporation or latent heat. (ρ)	External evaporation heat. (A p u)	Specific weight, *i.e.* weight of one cubic metre in kilograms.
Atmospheres.	Kilograms on square c/m.					
0·1	0·10334	46·2	46·3	538·8	35·5	0·0687
0·2	0·20668	60·5	60·6	527·6	36·8	0·1326
0·3	0·31002	69·9	69·7	520·4	37·6	0·1945
0·4	0·41336	76·3	76·5	515·1	38·2	0·2553
0·5	0·51670	81·7	82·0	510·8	39·6	0·3153
0·6	0·62004	86·3	86·7	507·1	39·0	0·3744
0·7	0·72338	90·3	90·7	504·0	39·4	0·4330
0·8	0·82672	93·9	94·3	501·1	39·7	0·4910
0·9	0·93006	97·1	97·5	498·6	40·0	0·5487
1·0	1·03340	100·0	100·5	496·3	40·2	0·6059
1·1	1·13674	102·7	103·2	494·2	40·4	0·6628
1·2	1·24008	105·2	105·7	492·2	40·6	0·7194
1·3	1·34342	107·5	108·1	490·4	40·8	0·7757
1·4	1·44672	109·7	110·3	488·6	41·0	0·8317
1·5	1·55010	111·7	112·4	487·0	41·1	0·8874
1·6	1·65344	113·7	114·4	485·5	41·3	0·9430
1·7	1·75678	115·5	116·3	484·0	41·5	0·9983
1·8	1·86012	117·3	118·1	482·6	41·6	1·0534
1·9	1·96346	119·0	119·8	481·3	41·7	1·1084
2·0	2·06680	120·6	121·4	480·0	41·9	1·1631
2·1	2·17014	122·1	123·0	478·8	42·0	1·2177
2·2	2·27348	123·6	124·5	477·6	42·1	1·2721
2·3	2·37682	125·1	126·0	476·5	42·2	1·3264
2·4	2·48016	126·5	127·4	475·4	42·3	1·3805
2·5	2·58350	127·8	128·7	474·3	42·4	1·4345
2·6	2·68684	129·1	130·1	473·3	42·5	1·4883
2·7	2·79018	130·3	131·3	472·3	42·6	1·5420
2·8	2·89352	131·6	132·6	471·3	42·7	1·5956
2·9	2·99686	132·8	133·8	470·4	42·8	1·6490

* The whole heat present in steam is $= q + \rho + A\,p\,u$.

TABLE FOR SATURATED STEAM—CONTINUED.

Pressure in		Temp. in degrees Celsius.	Heat of liquid. (q)	Internal evaporation or latent heat. (ϱ)	External evaporation heat. (A p u)	Specific weight, *i.e.* weight of one cubic metre in kilograms.
Atmospheres.	Kilograms on square c/m.					
3·0	3·10020	133·9	135·0	469·5	42·9	1·7024
3·1	3·20354	135·0	136·1	468·6	43·0	1·7556
3·2	3·30688	136·1	137·2	467·7	43·0	1·8088
3·3	3·41022	137·2	138·3	466·9	43·1	1·8618
3·4	3·51356	138·2	139·4	466·1	43·2	1·9147
3·5	3·61690	139·2	140·4	465·3	43·3	1·9676
3·6	3·72024	140·2	141·4	464·5	43·3	2·0203
3·7	3·82358	141·2	142·4	463·7	43·4	2·0729
3·8	3·92692	142·1	143·4	463·0	43·5	2·1255
3·9	4·03026	143·1	144·4	462·2	43·5	2·1780
4·0	4·13360	144·0	145·2	461·5	43·6	2·2303
4·1	4·23695	144·9	146·2	460·8	43·7	2·2826
4·2	4·34028	145·8	147·1	460·1	43·7	2·3349
4·3	4·24362	146·6	148·0	459·4	43·8	2·3871
4·4	4·54696	147·5	148·9	458·8	43·8	2·4391
4·5	4·65030	148·3	149·7	458·1	43·9	2·4911
4·6	4·75364	149·1	150·5	457·5	43·9	2·5430
4·7	4·85698	149·9	151·4	456·8	44·0	2·5949
4·8	4·96032	150·7	152·2	456·2	44·1	2·6467
4·9	5·06366	151·5	153·0	455·6	44·1	2·6984
5·0	5·16700	152·2	153·7	455·0	44·2	2·7500
5·1	5·27034	153·0	154·5	454·4	44·2	2·8016
5·2	5·37368	153·7	155·3	453·8	44·3	2·8531
5·3	5·47702	154·4	156·0	453·2	44·3	2·9046
5·4	5·58036	155·1	156·7	452·7	44·4	2·9560
5·5	5·68370	155·8	157·5	452·1	44·4	3·0073
5·6	5·78704	156·5	158·2	451·6	44·5	3·0586
5·7	5·89038	157·2	158·9	451·0	44·5	3·1093
5·8	5·99372	157·9	159·9	450·5	44·6	3·1610
5·9	6·09706	158·6	160·3	450·0	44·6	3·2122
6·0	6·20040	159·2	160·9	449·5	44·7	3·2632

2.—TABLE OF THE PRESSURE OF SATURATED STEAM FROM 0° TO 100° CELSIUS.

Temp. of steam in deg. Cels.	Pressure of the Steam.			Temp. of steam in deg. Cels.	Pressure of the Steam.		
	In millimetres column of mercury abs. pressure.	Corresponding Vacuum.	In abs. atmospheres.		In millimetres column of mercury abs. pressure.	Corresponding Vacuum.	In abs. atmospheres.
0	4·60	755·40	0·006				
1	4·94	755·06	0·006	26	24·98	735·01	0·032
2	5·30	754·69	0·007	27	26·50	733·05	0·034
3	5·68	754·31	0·007	28	28·10	731·90	0·037
4	6·09	754·00	0·008	29	29·78	730·29	0·039
5	6·53	753·46	0·008	30	31·54	728·45	0·041
6	6·99	753·00	0·009	31	33·40	726·60	0·044
7	7·49	752·50	0·009	32	35·35	724·64	0·046
8	8·01	751·98	0·010	33	37·41	722·59	0·049
9	8·57	751·43	0·011	34	39·56	720·43	0·052
10	9·16	750·83	0·012	35	41·82	718·17	0·055
11	9·79	750·21	0·012	36	44·20	715·80	0·058
12	10·45	749·54	0·013	37	46·69	713·31	0·061
13	11·16	748·84	0·014	38	49·30	710·70	0·064
14	11·90	748·10	0·015	39	52·03	707·96	0·068
15	12·69	747·30	0·016	40	54·90	705·10	0·072
16	13·53	746·46	0·017	41	57·91	702·09	0·076
17	14·42	745·58	0·019	42	61·05	698·94	0·080
18	15·35	744·64	0·020	43	64·34	695·65	0·084
19	16·34	743·65	0·021	44	67·79	692·21	0·089
20	17·39	742·61	0·022	45	71·39	688·61	0·093
21	18·49	741·50	0·024	46	75·15	684·84	0·098
22	19·65	740·34	0·025	47	79·09	680·91	0·104
23	20·88	739·11	0·027	48	83·20	676·79	0·109
24	22·18	737·82	0·029	49	87·49	672·50	0·115
25	23·55	736·45	0·031	50	91·98	668·02	0·121

PRESSURE OF SATURATED STEAM, &c.—(Continued.)

Temp. of steam in deg. Cels.	Pressure of the Steam.			Temp. of steam in deg. Cels.	Pressure of the Steam.		
	In milli-*metres* column of mercury abs. pressure.	Corre-sponding Vacuum.	In abs. atmos-pheres.		In milli-*metres* column of mercury abs. pressure.	Corre-sponding Vacuum.	In abs. atmos-pheres.
51	96·66	663·34	0·127	76	300·83	459·16	0·395
52	101·54	658·46	0·133	77	313·60	446·40	0·412
53	106·53	653·66	0·140	78	326·81	433·19	0·430
54	111·94	648·05	0·147	79	340·48	419·51	0·448
55	117·47	642·52	0·154	80	354·64	405·36	0·466
56	123·24	636·76	0·162	81	369·28	390·71	0·485
57	129·25	730·75	0·170	82	384·43	375·56	0·505
58	135·50	624·49	0·178	83	400·10	359·90	0·526
59	142·01	617·98	0·186	84	416·29	343·70	0·547
60	148·79	611·21	0·195	85	433·04	326·99	0·569
61	155·83	604·16	0·205	86	450·34	309·66	0·592
62	163·17	596·83	0·214	87	468·22	291·78	0·616
63	170·79	589·21	0·224	88	486·68	273·31	0·640
64	178·71	581·29	0·235	89	505·75	254·24	0·665
65	186·94	573·05	0·246	90	525·45	234·55	0·691
66	195·49	564·50	0·257	91	545·77	214·22	0·718
67	204·37	556·62	0·268	92	566·75	193·24	0·745
68	213·59	546·40	0·281	93	598·40	171·59	0·774
69	223·16	536·83	0·293	94	610·74	149·26	0·803
70	233·09	526·91	0·306	95	633·77	126·22	0·833
71	243·39	516·61	0·320	96	657·53	102·46	0·865
72	254·07	505·93	0·334	97	682·02	77·97	0·897
73	265·14	494·85	0·348	98	707·28	52·72	0·930
74	276·62	483·38	0·364	99	733·30	26·69	0·964
75	288·51	471·48	0·379	100	760·00	0·00	1·000

3.—BOILING TEMPERATURE OF SUGAR SOLUTIONS, ACCORDING TO FLOURENS.

105°	Cels. =	69·1 %	sugar.	114°	Cels. =	84·3 %	sugar.
106°	,, =	72·4 %	,,	115°	,, =	85·3 %	,,
107°	,, =	74·4 %	,,	116°	,, =	85·8 %	,,
108°	,, =	76·4 %	,,	117°	,, =	86·5 %	,,
109°	,, =	77·8 %	,,	118°	,, =	87·2 %	,,
110°	,, =	79·5 %	,,	119°	,, =	88·9 %	,,
111°	,, =	80·6 %	,,	120°	,, =	89·5 %	,,
112°	,, =	82·3 %	,,	125°	,, =	91·2 %	,,
113°	,, =	83·6 %	,,	130°	,, =	92·3 %	,,

4.—TEMPERATURE AT WHICH SOLUTIONS OF BEET JUICE MASSE CUITE OF VARIOUS DEGREES OF CONCENTRATION WILL BOIL, ACCORDING TO HORSIN DÉON, CONSISTING OF THE FOLLOWING :—

Sugar	79·75 %
Glucose	0·18 %
Ash	5·55 %
Organic Substances	9·02 %
Water	5·52 %

Saccharometer *indication.*	Specific weight.	Boiling temperature.
23·1	1·14	101° Cels.
42·0	1·19	102° ,,
54·8	1·26	103° ,,
61·7	1·30	104° ,,
64·2	1·34	105° ,,
71·4	1·36	106° ,,
74·5	1·38	107° ,,
77·6	1·40	108° ,,

5.—SATURATED SUGAR SOLUTIONS AT VARIOUS TEMPERATURES, ACCORDING TO FLOURINS.

0° Cels.	= 64·7 %	sugar.		60° Cels.	= 74·0 %	sugar.
10° ,,	= 65·5 %	,,		70° ,,	= 76·1 %	,,
20° ,,	= 66·5 %	,,		80° ,,	= 78·4 %	,,
30° ,,	= 68·0 %	,,		90° ,,	= 82·5 %	,,
40° ,,	= 69·7 %	,,		100° ,,	= 82·5 %	,,
50° ,,	= 71·8 %	,,				

6.—SPECIFIC HEAT OF VARIOUS SOLUTIONS.

Saccharometer	Spec. weight.	Spec. heat.
Water	1	1
16·6%	1·0685	0·9
31·6	1·1370	0·8
44·9	1·2055	0·7
57·3	1·2740	0 6
68·6	1·3425	0·5

EXTRACTS

FROM

MONS. E. PECLÉT'S

TREATISE ON HEAT.

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Vol. 2.	-	-	-	Chapters	1 to 8.
„ 3.	-	-	-	„	1 to 4.

VOL. 2. BOOK IX. PAGE 301.

EVAPORATION.

*1557. Distillation and evaporation are both for the purpose *of separating one or several volatile* substances, mixed or combined with fixed or less volatile substances; *but in distillation the object is to collect the volatile* substances, whilst in evaporation it is the exact opposite, viz. :—*to collect the fixed or less volatile substances.*

1558. Evaporation and distillation have another essential difference; distillation can only be effected by boiling, and at a temperature varying with the pressure; evaporation, on the contrary, can be produced under the same pressure at all temperatures, at least when it takes place in open vessels in which the air can easily be renewed. Evaporation in a closed vessel is really distillation.

1559. Evaporation may be effected in a variety of ways, which are all comprised under the following names :—

Spontaneous evaporation in open air;

Evaporation of a liquid at the ordinary temperature by a current of forced air;

Evaporation in open vessels by the direct action of a furnace;

* These numbers refer to the paragraphs in Mons. Peclet's Work.

Evaporation of a hot liquid by a current of forced air;

Evaporation by *steam*;

Evaporation *in vacuo*;

Evaporation by multiple effet:

We will examine these methods successively.

CHAPTER I.

SPONTANEOUS EVAPORATION IN OPEN AIR.

1560. This method is chiefly used for concentrating solutions of sea salt. Let us first examine the phenomena which accompany it, in order to deduce from them the most favourable circumstances.

1561. When a liquid is exposed to the air, the air above it is saturated with vapour, becomes lighter, rises, and is soon replaced by fresh layers of air, which, after being saturated, rise in their turn, and so on. By this means, two currents are formed, one being the layers saturated, which rise, the other, the layers in their natural state, which descend on the liquid. This motion is exactly similar to what takes place in a mass of air or water, heated from below. The *quantity* of vapour supplied by the liquid to the surrounding air is in proportion to the difference between the pressure of the liquid and *that of the vapour already existing in the air. Therefore*, everything being otherwise equal, the evaporation at the same time will be greater as the liquid is hotter, and as the air is less saturated. It is evident, if the air is already saturated with steam, no evaporation can take place; this must always take place after a certain time, when the air above the liquid does not communicate freely with the atmosphere; as it soon becomes saturated, and the evaporation, which, up to this moment, has been continually decreasing, then stops completely.

1562. If the air is much agitated, the layers which become saturated at the surface of the liquid, renew themselves much more quickly than if their motions were simply due to the variations of density; consequently, the evaporation is much more rapid. It is further evident that the evaporation only taking place at the surface of the

liquid itself, everything else being equal, the effect produced in a given time must increase with the extent of this surface.

1563. From this we may conclude that spontaneous evaporation is *more active*; 1st, when the free surface of the liquid is more extended; 2nd, when the temperature of the liquid and of the air, or one of the two, is higher; 3rd, when the air is dryer; 4th, when the air is more agitated.

1564. When the apparatus is of large size, only one of the preceding elements, viz., the extent of surface of the liquid is under our control, and we are obliged to submit to the influence of all the variations of the other elements, occasioned by the changes which take place in the state of the atmosphere; only, we can take care to chose the hottest season of the year, and the most favourable exposure. Up to the present only two methods of spontaneous evaporation have been used, and have both been applied to the extraction of sea salt.

1565. The first consists in exposing the solution to the air in large shallow vessels; the liquid is raised into these vessels by a steam pump. In the centre of France, the operation usually commences in the month of March and terminates in September. The pans are lined with clay, and usually of two kinds; the first, larger and deeper than the others, receive the new waters, which are then concentrated to saturation; the others, very shallow, receive the water from the first, and deposit the crystals in them.

1566. The second method of evaporation consists of filling with hurdles, an open wooden structure, above which the waters to be evaporated are raised, so that they may fall through the hurdles; the water, divided by the numerous obstacles which it encounters in its fall, presents a large surface to the air, and experiences, especially when the air is dry and agitated, a rapid evaporation. These apparatus are called graduated structures; they are much better than the first method described, because they are sheltered from the rain, and need only be used when the circumstances are favourable.

1567. In all spontaneous evaporations, the heat necessary for the evaporation is supplied by the liquid and by the air; the evaporation only costs the interest of capital

laid out in ground, buildings, engines, price of labour, and of a certain quantity of fuel when the waters are raised by steam pumps. The cost of spontaneous evaporation is much less than when heat is used; in fact, according to Mr. Payen, the cost of extracting 100 kilos of salt in the salt marshes varies from 0fr. 60 to 2fr. 60, according to the *locality and the atmospheric circumstances accompanying* the operation; therefore, sea water containing 0·025 of sea salt, to extract 100 kilos of salt, it would be necessary to evaporate 3,900 kilos of water, which would require 3,900÷6=650 kilos of coal, which, at 30 fcs. per ton, would cost 19 fr. 50.

1568. Spontaneous evaporation cannot be produced in all solutions of salts or other matters soluble in water, because there is a large number of substances, which, having a great affinity to water, will not cede it to the air except when they contain a large quantity of it; when they are in highly concentrated solutions, not only will *spontaneous evaporation not take place, but on the contrary*, some of them absorb the humidity of the air. These must be evaporated by heat.

CHAPTER II.

EVAPORATION OF A LIQUID AT THE USUAL TEMPERATURE BY A CURRENT OF FORCED AIR.

1569. Spontaneous evaporation of liquids in the open air increases, as we have seen, when the surface of the liquid is larger, when the air renews itself more rapidly, and when it is dryer and hotter.

1570. The majority and even the whole of these circumstances may be brought together artificially; the movement of the air requires an expenditure of motive power, the drying requires that of a hygrometric substance, and its heating, that of fuel. I don't think that anyone has yet tried to evaporate with a forced current of air, dried and heated. But, evaporating with a current of atmospheric air in its ordinary state, Montgolfier made some experiments, which are very interesting. They were described by Clément Désormes in a memoir inserted in the Annales de Chimie, Vol. LXXVI.

1571. Montgolfier's idea was to concentrate grape-cakes before their fermentation, retaining in them all their fermentable principles, so that they could be transported at little cost, and converted anywhere into wine, by diluting them with a sufficient quantity of water, and leaving them to ferment. To bring about this result, a rapid concentration and a low temperature were necessary. The principle of Montgolfier's apparatus is the same as that on which the graduated structures, of which we have already spoken, are based, except that the liquid after being split up into parts, is traversed by a current of air produced by an engine. The first trials took place in 1794; Montgolfier made various fruit preserves, amongst others of apples and grapes. Of the former he made a large quantity, more than 1,500 kilos, which had a very agreeable taste. In 1879 he repeated his experiments at Paris, with equally satisfactory results. Montgolfier found *out, that in the usual state of the air in autumn, it contains* on an average three grammes of water per cubic metre. Therefore, a man in a day's work, consisting of six hours of effective labour, can give, with the aid of a machine, 5 metres of velocity to about 70,000 cubic metres of air. The quantity of air which he could evaporate will therefore be $70{,}000 \times 0^{k}\ 003 = 210$ kilos. Supposing a *day's pay be 1 f. 50, the evaporation of 100 kilos of water* would cost $\frac{1{\cdot}50}{2{\cdot}10} = 0$ fr. 71. Admitting that sugar forms a quarter of the grape malt, the concentration of 400 kilos of syrup would cost 2 fr. 10. But this expense may be considerably reduced, by diminishing the velocity of the air, as it is known that the live force, which is really what is consumed and paid for, increases in the square of the velocity; therefore, by reducing the velocity one half, it would be possible, with the same labour, to quadruple the mass of air set in motion.

1572. Many kinds of apparatus may be used to produce the current of air which must traverse the liquid, the simplest being the centrifugal force ventilator. Clément invented an apparatus for evaporating juices, in which they flowed on peeled switches, made of white wood, arranged in regular layers, and crossed alternately in a vessel which was traversed by a current of air obtained by means of a ventilator worked by the hand. The apparatus was badly arranged, and of no practical use. A much greater effect could be obtained by drying the air with

lime, or heating it to a temperature between 50 and 100°, which could not in any case do any harm to the juices, inasmuch as a large portion of the heat of the air would be used to form vapour, and not to heat the liquid. A chimney, in which the draught would be produced by the heat not utilised in heating the liquid and air, might be used without inconvenience to raise the temperature of the liquid, and instead of the mechanical work. We will return to this subject later on.

CHAPTER III.

EVAPORATION IN OPEN VESSELS BY THE DIRECT ACTION OF A FURNACE.

1573. All evaporation in open air by means of heat is carried on, by placing the pan which contains the liquid to be evaporated, on a fire, or by exposing it to a current of hot air. When a liquid is in contact with the air, the evaporation is generally manifest, even before the liquid commences to heat, as we know that liquids emit vapours at all temperatures; but this evaporation is extremely slight. As the liquid warms, the evaporation goes on increasing, and a portion of the heat received by the liquid, is lost by this evaporation; consequently, the temperature of the liquid increases much more slowly than if the vessel was closed. It may even happen that the liquid never reaches boiling point; indeed, if the surface of the liquid exposed to the air is relatively very large to the quantity of fuel burnt, the evaporation, which is proportional to the surface, might, at a certain temperature of the liquid, carry away a quantity of heat equal to that received by the liquid from the fire, and consequently the temperature of the liquid would remain constant.

1574. In all cases, whether or not the liquid reaches boiling point, it is generally admitted that the quantity of heat necessary for the evaporation is the same; nevertheless, it is not so always, this quantity increases rapidly, according as the temperature is lower, which is accounted for by the heat lost in heating the air and by radiation. The first loss increases with the lowering of the temperature, because the volume of air required to dissolve a given weight of vapour, increases rapidly as the

temperature is lower; and it can be easily calculated, (these calculations will be made when we come to speak of drying with hot air); as to the loss by radiation, it cannot be calculated, it being understood that, when evaporation is very lively, the vapours condensed in the air, the temperature of which differs very little from that of the liquid, should, by radiating on the liquid itself, reduce this loss to next to nothing.

1575. To determine the quantities of heat employed to evaporate water at different temperatures, I made the the experiments which I am going to describe. I suspended on a very sensitive balance, a cylindrical vessel of white metal 0m. 30 diameter, and 0m. 05 deep, placed in another of larger diameter and greater depth; the first was sustained in the second by three cork plugs, and the space between the two was filled with carded cotton; the inside vessel was filled with hot water, and I noted the cooling which this water experienced in successive losses of weight of 10 grammes.

The temperatures noted were as follows:—

58°25 55°25 52°00 48°50 44°75 40°75 36°25 31°25

Therefore the reductions of temperature, corresponding to the diminutions of weight of 10 grammes, were:—

3° 3°25 3°50 3°75 4° 4°50 5°

As the cooling of the vessel at the bottom and sides could be neglected, and the weight of the hot water at the beginning was 2k 413, a very simple calculation shows that the quantities of heat absorbed to evaporate 1 kilo of water were:—

From	58·25°	to	55·25°	—	724	units.
„	55·25°	„	52·00°	—	780	„
„	52·00°	„	48·50°	—	837	„
„	48·50°	„	44·75°	—	893	„
„	44·75°	„	40·75°	—	949	„
„	40·75°	„	36·25°	—	1063	„
„	36·25°	„	31·25°	—	1176	„

The external temperature was 15°. Therefore, as we have said, the quantity of heat absorbed to evaporate 1 kilo *of liquid increases rapidly as the temperature of the liquid decreases.* Experiments made on a large scale completely confirm this fact.

In taking the mean temperatures of the experiments and tracing a curve, we find, the air being at 15°, that the quantities of heat absorbed by the evaporation of 1 kilo of water, the liquid being at—

20° 30° 40° 50° 60° 70° 80° 90°

Are represented approximately by the numbers 1370, 1160, 1070, 840, 760, 720, 690, 660.

ARRANGEMENT OF THE APPARATUS.

1576. The apparatus used for evaporating solutions in open vessels is arranged in a similar way to those used for generating vapour, only that the pan is open. The furnace is at one end of the vessel, and under it, and the hot air circulates under the remainder of the vessel in flues, which carry it under the whole extent of the vessel. The quantity of fuel required to produce a given effect in a given time may be calculated by taking as a basis that the evaporation of 1 kilo of water absorbs the quantities of heat corresponding to what we have just indicated. But much larger heating surfaces should be used, as much heat can be got from the smoke: for this purpose very large chimneys should be used, so as to overcome the friction arising from the length of the flues. As a general rule several vessels are placed in succession, the liquid inside them receiving a decreasing amount of heat, and are often so arranged as to pass the liquid from one vessel into the preceding one.

1577. There is no economy of fuel in making the vessels very deep, for if the evaporation takes place at the temperature of ebullition, the quantity of vapour produced depends entirely for the same consumption of fuel, on the extent of surface exposed to the direct action of the furnace, or to the current of hot air; and when the evaporation takes place at a lower temperature, the quantity of vapour produced depends on the quantity of heat which penetrates into the vessel, and on the temperature of the evaporation, which temperature itself depends on the free extent of the surface of the liquid. Therefore the quantity of the liquid has no influence. In the latter case, the vessels being deep, tends to diminish the differences of temperature arising from variations in the intensity of the furnace, but the permanence of the temperature is seldom of any importance.

1578. When the evaporation takes place at boiling temperature, the extent of the free surface of the liquid, has, as we have said, *no influence on the evaporation*; the same amount of vapour is formed for the same consumption of fuel when the vessel is open, when it is closed *a small opening must be left for the vapour to escape*, if the cover is fastened on the vessel, the exhaust pipe for the vapour must be of sufficient dimensions to *prevent the pressure of the vapour exceeding that of the atmosphere*. Therefore, when contact with the air is prejudicial to the liquid under evaporation, the vessel may be closed in such a way as to leave only a sufficient exit for the vapour, and thus prevent the air being renewed.

It may, however, be imagined that in vessels which are not closed there would be a loss of heat by the radiation of the surface of the boiling liquid; but this loss, as we have already pointed out, would be very slight; as it is compensated for by the radiation of the vapour above the surface, which immediately becomes blistered. In closed vessels, on the contrary, there is a very large loss of heat by the cooling of the upper part; this loss may be estimated at 1 k 50 of vapour per square metre per hour; therefore, it will always be as well to cover this part with non-conducting material.

1579. The form of the vessels, the extent of their surface, and the nature of the metal, necessarily depend on the nature of the liquid to be evaporated, and it is therefore impossible to make any general observations on these points. But it will always be easy, remembering the details given in the chapter on generating vapour, to determine, in each special case, the dimensions of the vessels, and the most advantageous way to erect them. We will now describe the apparatus which are most used.

1580. In salt works, very large vessels are used, heated at the bottom. At Dieuze, they have four rectangular pans of equal dimensions, made of sheet iron 0 m. 004 thick, and 0 m. 50 high, the edges of which are flanged back at right angles and fastened with bolts, the joints being cemented. These pans are 25 metres long by 5 wide, and rest on cast iron pillars 1m. 35 high, above them is an immense flue made of wood, which conducts the vapours into the chimney, which is also made of wood; the smoke spreads freely under the vessels, meeting no

obstacles. Each furnace burns 2,500 kilos of coals per 48 hours, or 52 kilos per hour, and 0^{k} 46 per square decimetre of grate. Each square metre of heating surface produced 28 kilos of vapour. The temperature of the smoke on entering the chimney was 100°; the useful effect being 7^{k} 50 of water evaporated per kilo of coal. Another vessel, 16 metres long by 7 metres wide, working in the same manner as the four which we have just mentioned, gave the same results, and another, 27 m. 5 long and 7 metres wide, did not produce such a good effect.

The results obtained by operating at boiling point or at a lower temperature, are very different. At boiling point, 36 to 38 kilos of coal are burnt to obtain 100 kilos of salt; at a lower temperature 42 to 44 kilos would be required. The difference arises from the heat absorbed by the air and from the radiation of the liquid surface.

In spite of the great length of these vessels there is not a great difference in temperature between the part above the fire and the other end. When the liquid is not brought to boiling point, the temperature above the fire is 80°, and 50° to 60° at the other end.

1581. Figures 9 and 10 represent two vertical sections

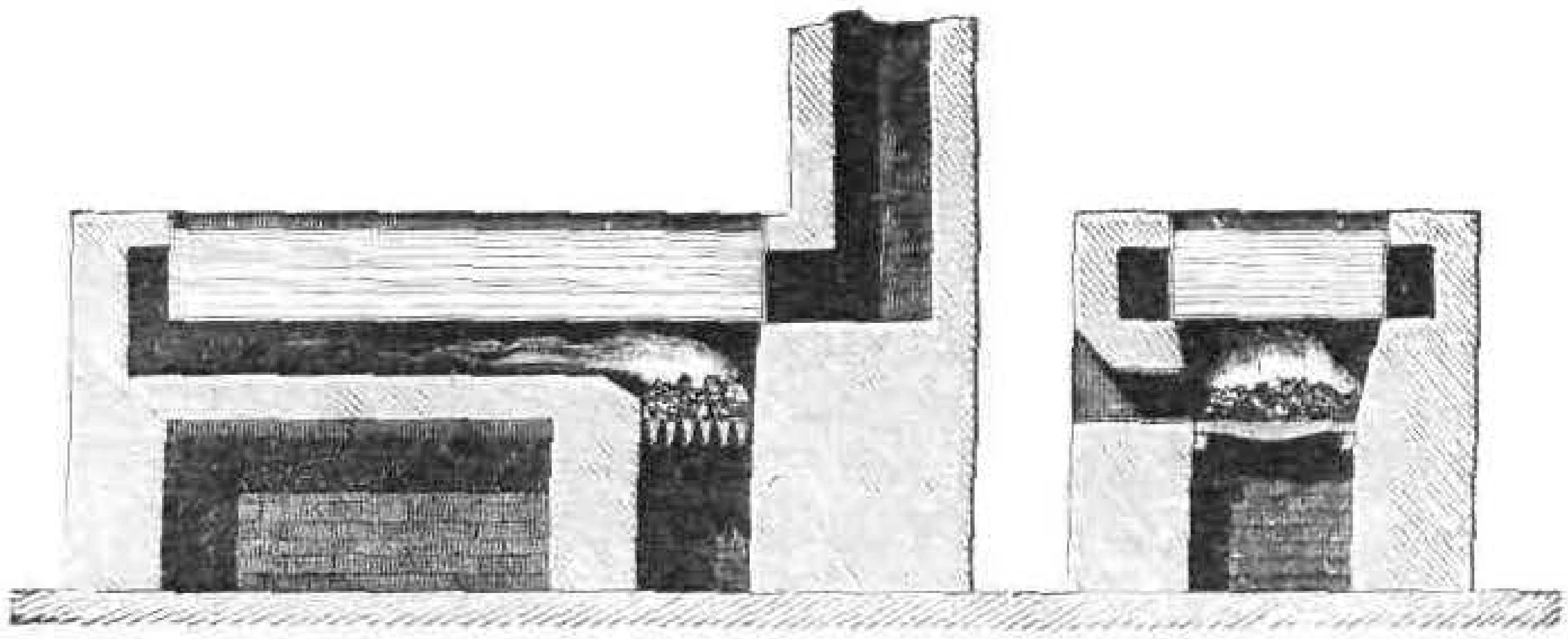


Fig. 9. Fig. 10.

of an evaporating vessel; the hot air, coming from the furnace, circulates under the vessel, returning along each side into the chimney. If the furnace was at the other end, the current of hot air would have to circulate successively over the two sides of the vessel.

The vessels usually used for concentrating sulphuric acid are of lead, and rest on cast iron jointed plates, which receive the direct action of the heat; only the bottoms of

the vessels are heated, the hot air being circulated through partitions made of bricks. There is no advantage in this arrangement, and it has the drawback of reducing the draught. It would be more advantageous to do away with these partitions, and to arrange the exit for the smoke so that the top of it was a little below the bottom of the vessel, thus forming a permanent layer of hot air ; the heating would then be more uniform. With these kinds of vessels, the grates are often made with a very large surface, so as to allow of slow fires being used, which cannot damage them. They are also often heated by the heat lost from the pyrites ovens.

1582. When the liquids to be evaporated produce deposits, the accumulation of which might damage the vessels, these are often made in a conical shape (fig. 11).

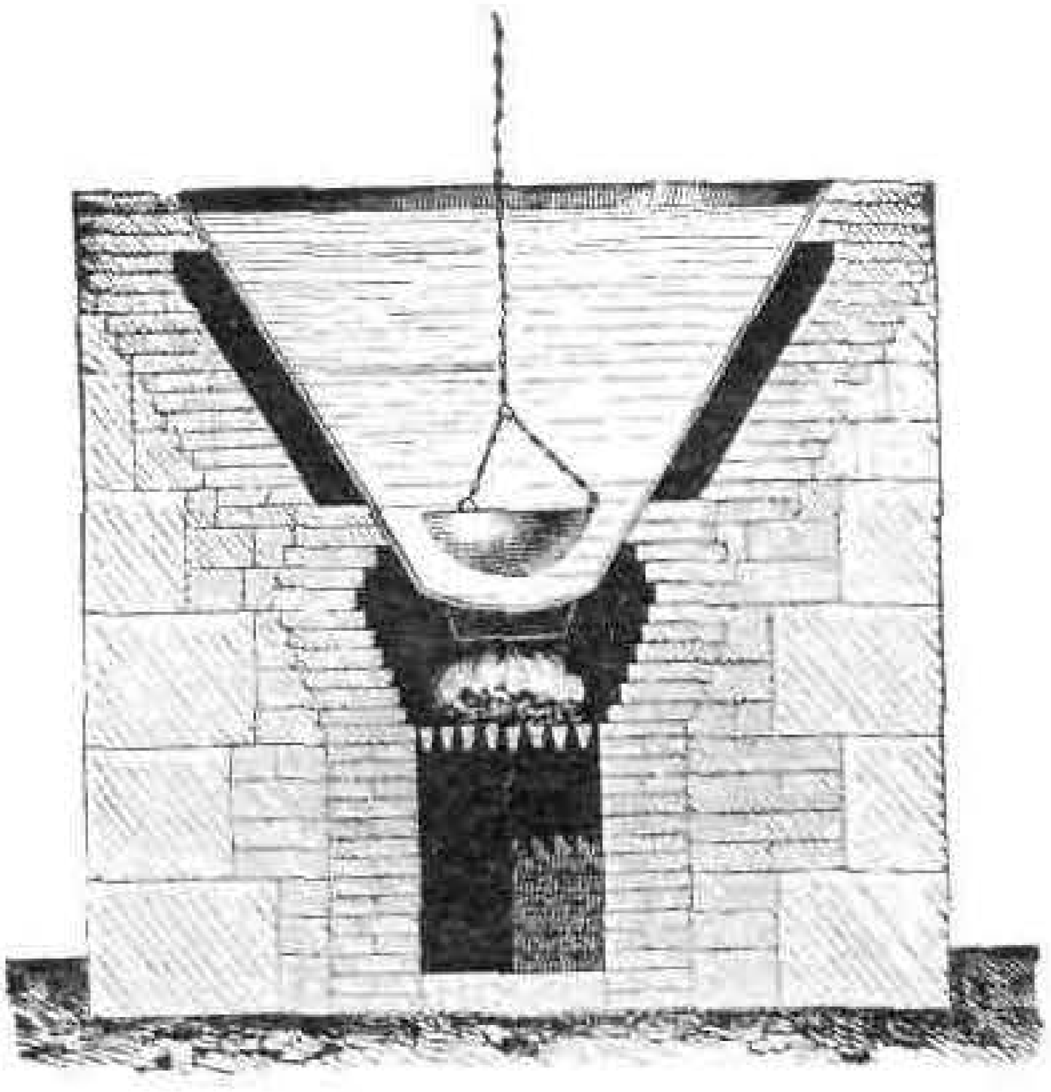


Fig. 11.

A metal pan, with a number of small holes in it, is suspended by a chain, at a short distance from the bottom, and the movement of the liquid being much slower inside the pan, the deposits are formed there, and can easily be extracted by withdrawing the pan.

1583. If the matter deposited was in large quantities, this arrangement would not answer, as the matter precipitated to the bottom of the vessel which receives the direct action of the fire, might burn it. In this case it would be better to use some other arrangement.

1584. Figure 12 represents one of these arrangements. The bottom of the vessel is undulated, and only the upper

part of these undulations is heated; the flues follow the undulations in order that the smoke may extend over the

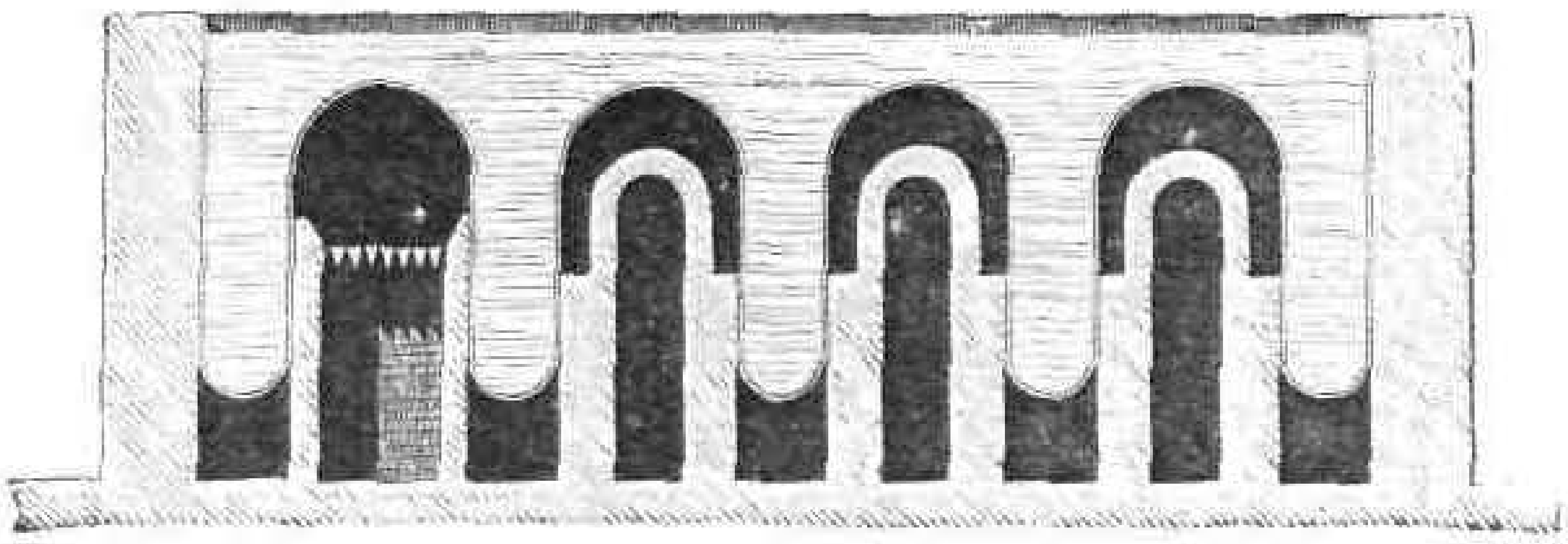


Fig. 12.

whole heating surface; they communicate between each other through the surrounding brickwork.

Figure 13 represents a vessel in which the furnace and the flues are inside, and the deposits also accumulate on the part inside which is not heated by the gases. If

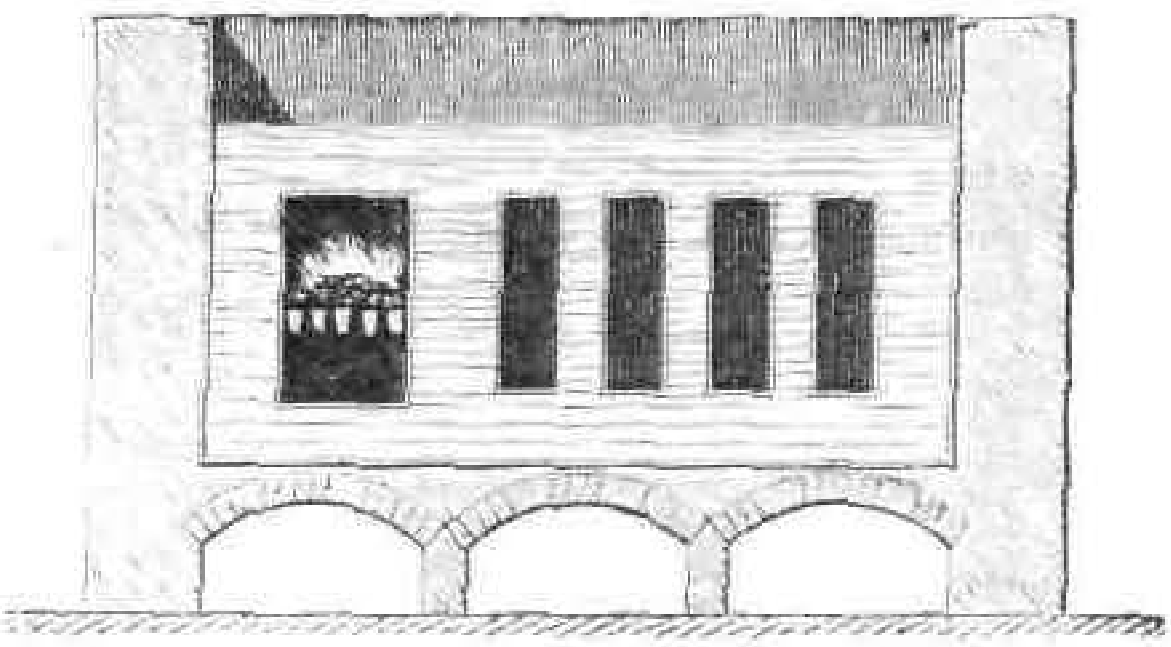


Fig. 13.

deposits form on certain parts of the vessel heated by the gas, these should be made with a curved surface; the deposits could then be more easily removed than if they were angles or flat surfaces, and there would be less danger of burning the vessel.

1585 When the evaporation has to take place at a high temperature, as in dissolving carbonate of soda, a series of vessels placed one above the other is used (fig. 14). The first, which is either direct above the fire, or upon a brick arch, is intended either to produce or terminate the evaporation; the others, to commence it, or at least to heat the liquid. Each vessel has to feed the succeeding one, and, for this purpose, has a valve, or better still, a

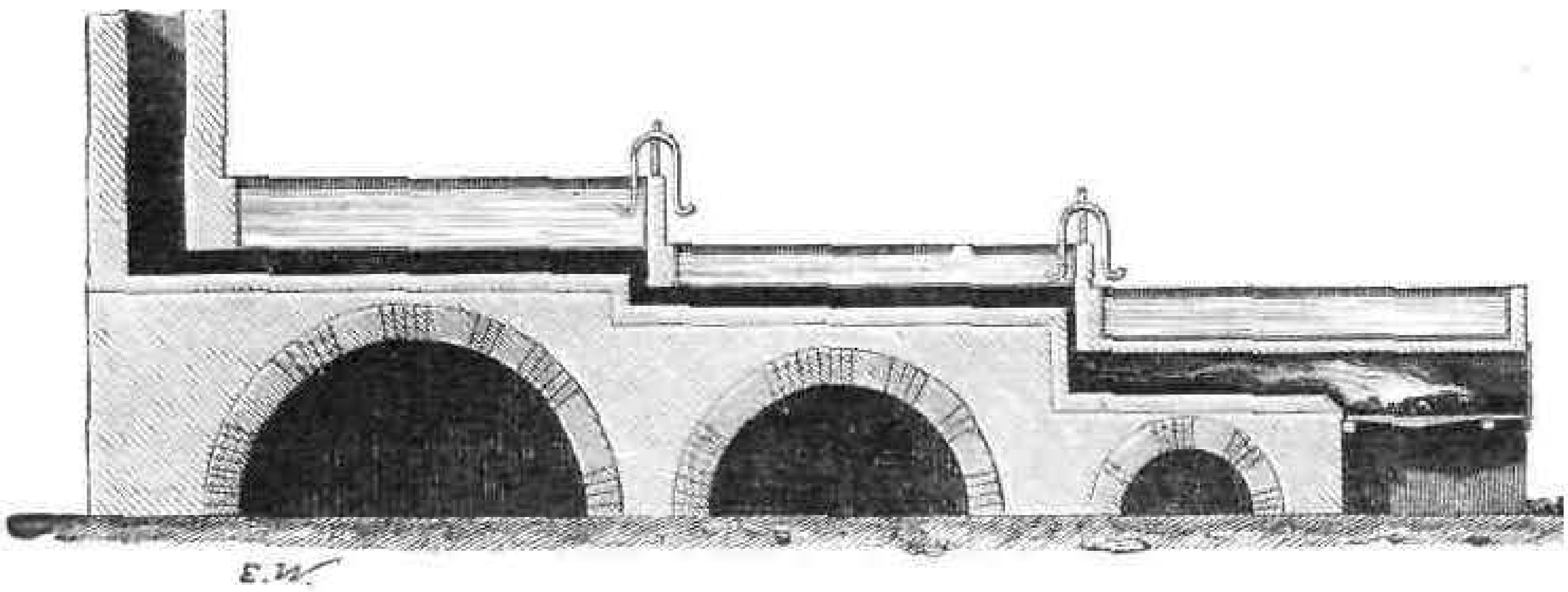


Fig. 14.

syphon always primed, which works when lowered, but stops the liquid flowing when it is raised. The simplest plan for these syphons is to have a pipe with two equal branches parallel to each other, and with the ends turned up ; it is evident that the tube being full of liquid, and the ends being at the same height, it will remain full ; but if one of the branches is dipped in one of the vessels, the column being shortened, the liquid will flow through the other branch.

1586. In what we have said, we have chiefly considered evaporation from the standpoint of economy of fuel, but there are circumstances in which time is a much more important element, and in which it is advisable to sacrifice fuel to accelerate the evaporation. We may take the concentration of syrups as an example of this, because the longer sugar remains under the action of heat, the more it deteriorates.

SWING VESSELS.

1587. The apparatus which have long been used for concentrating syrups, consisted entirely of shallow vessels, in which the syrup was placed, receiving the heat direct from a furnace, the smoke going direct to the chimney, not circulating round the vessel ; this arrangement was anything but economical as regards fuel, and bad on account of the deterioration of the sugar ; if the vessel remained on the fire after the required degree of concentration was arrived at, the evaporation being very rapid, the syrup deteriorated, the result being that less white sugar and more molasses was obtained.

This drawback has been overcome by using swing vessels, which can be raised and emptied at the exact moment when the concentration is complete; this apparatus (fig. 15) consists of a flat vessel, A, with a large spout, which juts out from the furnace, over a large copper tank, C, called a cooler in which the boiled syrup is collected and commences to crystallize; the reservoir, D, above the vessel, contains the syrup to supply the vessel for boiling to grain; the chain, E, works on two pulleys and raises one end of the vessel to empty the contents into the cooler; the supply reservoir has a pipe attached to it, closed inside by a valve, *m*, which is also worked by a chain. The grate of the furnace has a very large surface, in proportion to the bottom of the vessel, the smoke from it passes through a number of orifices, *o*, *o*, *o*, into a circular flue, G, which communicates with two chimneys. As soon as the syrup is sufficiently concentrated, a workman swings the vessel by pulling the chain E; it empties itself into the cooler, during the whole time of this operation it is out of reach of the action of the fire. As soon as the syrup has flowed out, the valve of the reservoir is opened, and the vessel refilled immediately. By this method only a small quantity of syrup need be boiled at once, and, by multiplying the operations, a great benefit may be obtained, as prolonged action of heat and air does harm to the quality of the syrup. It is easily understood, that by multiplying the boilings, their duration decreases, and, consequently, each portion of syrup remains a less time exposed to the action of the heat and air.

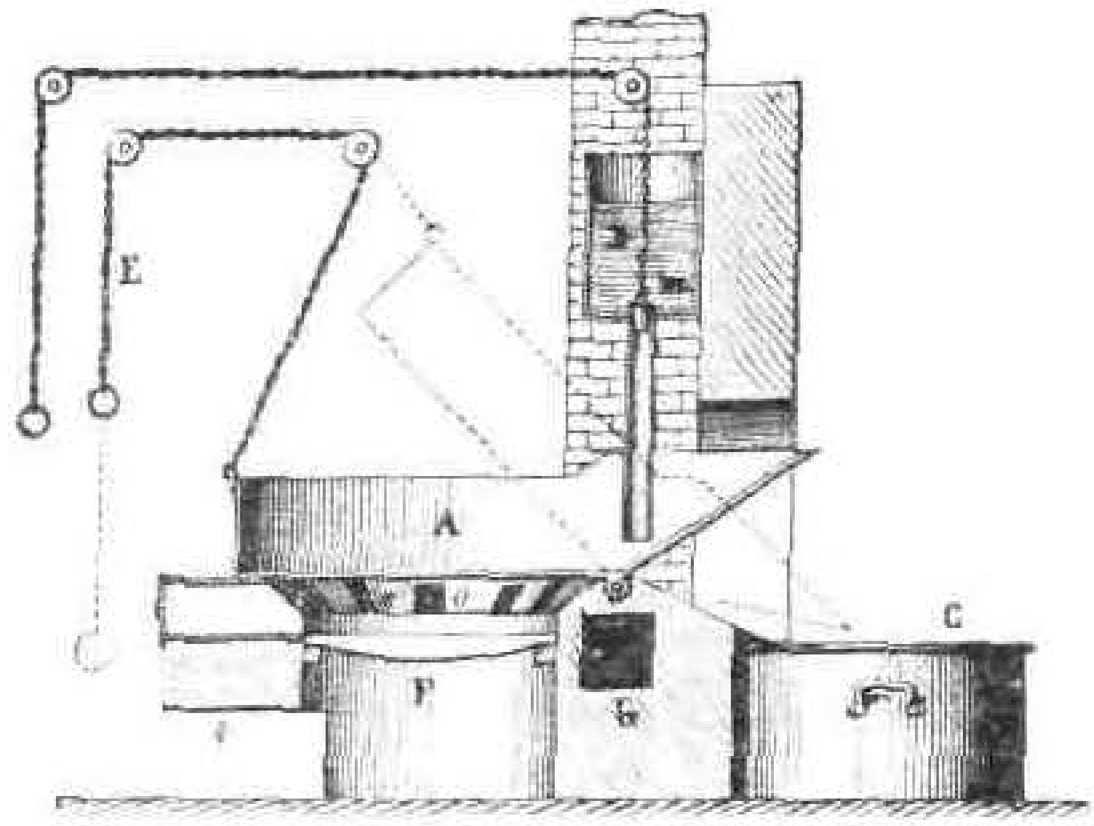


Fig. 15.

But there is an enormous expenditure of fuel, as the furnace is very large, and the hot air arrives in the chimney at a very high temperature. At the present time heating by steam is exclusively used; it is more beneficial, preserving the sugar better, and consuming less fuel.

APPARATUS FOR EXHAUSTING VAPOURS.

1588. In factories where evaporation is carried on on a large scale, the enormous quantities of steam which escapes and partially condenses is often very troublesome, and by saturating the air, retards evaporation at a lower temperature than boiling point. To get over this difficulty, a very simple contrivance has been invented: the vessel is covered with a dome usually made of wood, open in front, and provided at the end of the vessel with a vertical pipe, which enters the chimney at a certain height, but only for a certain part of its width; the current of air, which the force of the smoke ascending determines, draws in the vapours, which consequently cannot spread into the works. But this arrangement, in spite of a large increase in the area of the chimney, may impede the draught; to prevent this, a large chimney should be built, communicating with the case of the vessel; it should only be raised 8 or 10 metres high, as above that, the smoke and air charged with vapour become mixed. Sometimes the vessel is surrounded by a sort of funnel, open at three sides, and communicating with another chimney which surrounds that from the furnace. But this contrivance is not so good as the previous one, as too much air is drawn in, and a portion of the vapour may still escape into the works.

1589. It may be enough to discharge the air mixed with vapour into a special chimney of large area; however, if the mixture is cooled sufficiently in the chimney to condense a portion of the vapours, these, suspended in the air, might give it, in spite of its elevation of temperature, a density greater than that of the surrounding air, and the upward movement of the mixture would not take place, notwithstanding the large air opening into the factory; but nearly always the heat thrown off by the condensation is sufficient to give to the mixture a certain upward motion.

1590. It is evident that, if evaporation takes place at boiling point, the vessel being closed, a simple pipe communicating with the vessel, and opening outside, would suffice to discharge the vapour, no matter what its direction.

1591. In order to discharge the vapours by the furnace chimney, it has been proposed to supply the furnace with air charged with steam by passing it over the vessel,

which is fitted with a cover slightly raised, and open in front, by which the outside air reaches the liquid; the air descends through a channel into the ashpan, and then into the furnace under the vessel, and into the chimney. The great drawback to this arrangement is that a much larger volume of air than is necessary for the combustion passes into the furnace; to burn 1 kilo of coal, 18 cubic metres of cold air are required; admitting that each kilo of coal evaporates 6 kilos of water, and that the evaporation takes place at 50°, at this temperature 11·72 c.m. of air at 0° are required to remove the vapour from 1 kilo of water, the volume of air drawn into the furnace, reduced to 0°, would be $6 \times 11 \cdot 72 = 70 \cdot 32$ c.m. There would therefore be a great excess of air, if evaporation took place at a low temperature. Furthermore, the great quantity of vapour contained in the air, passing into the furnace, would be very unfavourable to a good combustion, and would occasion a great loss of useful effect.

CHAPTER IV.

EVAPORATION OF A HOT LIQUID BY A FORCED CURRENT OF HOT OR COLD AIR.

1592. In this method of evaporation, two different ways may be adopted; the air may be passed over the liquid in thin layers, or small bubbles may be sent through the liquid. In either case, the liquid, or the air, or both, may be heated.

1593. The simplest arrangement for evaporating a hot liquid by a current of cold air is represented in figures 16 and 17. A A is a rectangular vessel, closed at the top and ends by wood or metal plates, the space between the top of the liquid and the upper plate is open in front, and communicates at the opposite side with a large chimney. The fire heats the lower part by radiation, and the sides by the current of smoke, which passes through an iron pipe into the chimney. Between the liquid and the top of the vessel there are two parallel sieves, made either of canvas or metal, stretched tight, placed very near each

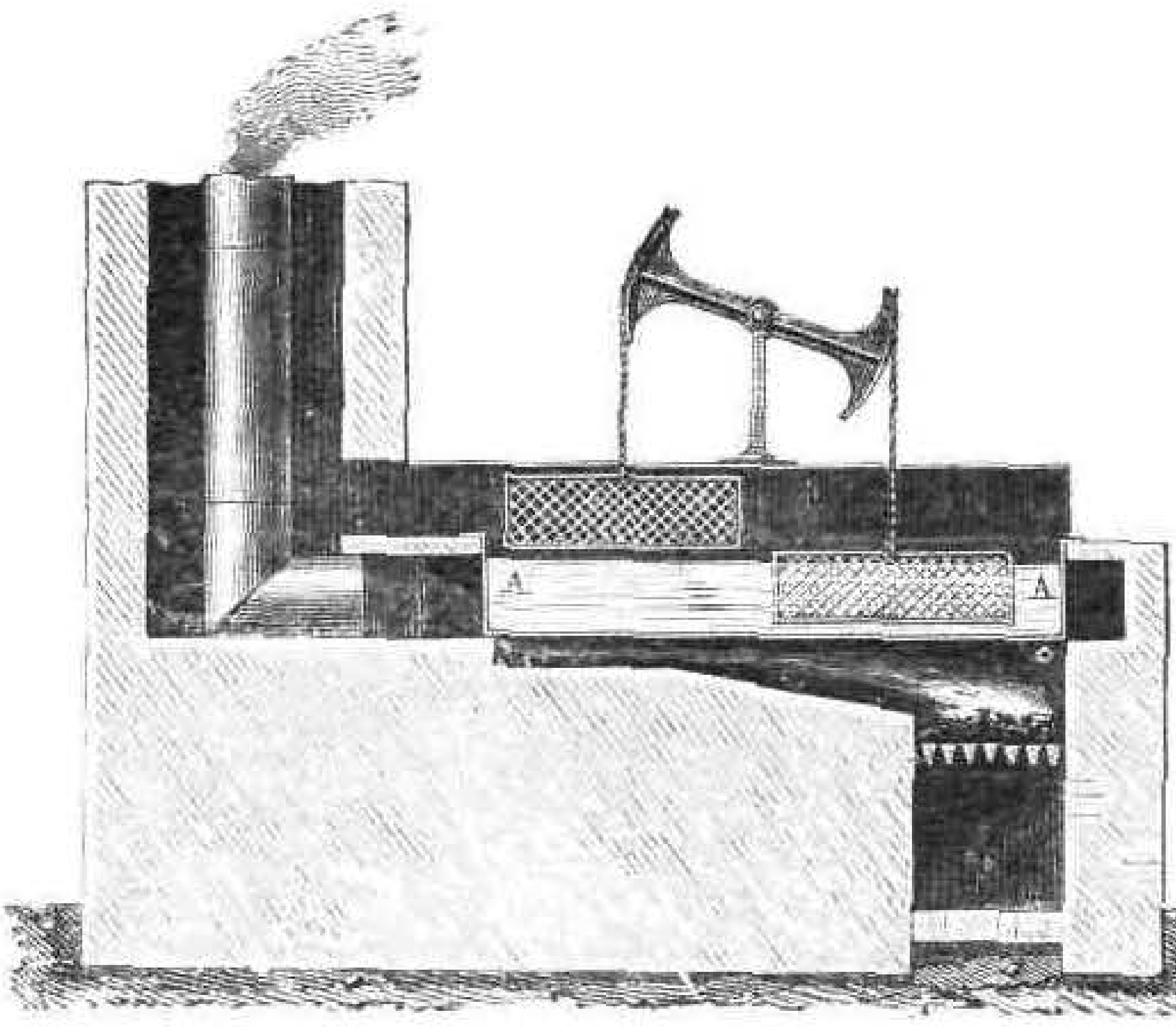


Fig. 16.

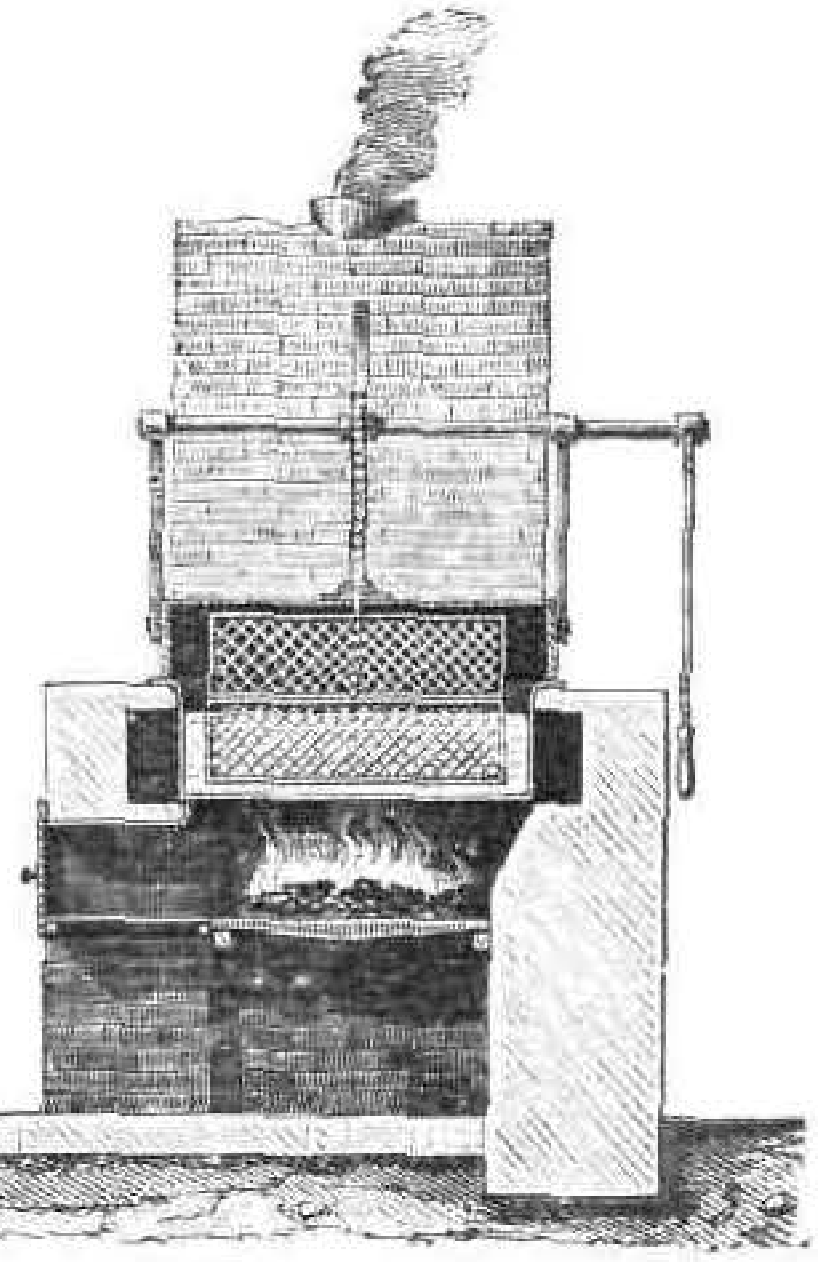


Fig. 17.

other; these are attached to the two extremities of a balance in such a way that when one end is up the other is dipped into the liquid. The air is thus forced to pass through wet net-work, which may be saturated as often as required. This apparatus is not now used.

1594. For the same purpose it has been proposed to use a horizontal cylindrical vessel, the upper part of one end communicating with the air and the other with a chimney, the vessel to be fitted with a revolving serpentine the part of which rotates in the liquid, and is supplied with high pressure steam. By this arrangement the liquid in the vessel and that which comes in contact with the serpentine are boiling; this apparatus is really only for the purpose of exhausting the vapours. It would only be applicable to the case we are considering, inasmuch as the vapour would not heat the liquid, except at a lower temperature than its boiling point; at the same time, the apparatus I have just described is a very good one, on account of its simplicity.

1595. Figures 18 and 19 represent a similar arrangement to the last one. Figure 18 is a section taken longitudinally, and 19 a cross section through XY. Wet sheets are wrapped round a revolving shaft; the movement of the air is produced by a ventilator, and the heat of the

smoke, on leaving the furnace, is used to heat the air from the ventilator. A is the furnace, B the flue, at the end of which the smoke divides, so as to heat simultaneously the two sides of the vessel; D, a case containing a large number of horizontal tubes through which the air from the ventilator E passes; the smoke circulates amongst the tubes and passes into the chimney F; G, the vessel in which the cloths attached to the shaft HH dip, so as to form several prismatic concentric surfaces; I, chimney to carry off the air charged with vapours. The ventilator and the pulley K are set in motion by some motive power.

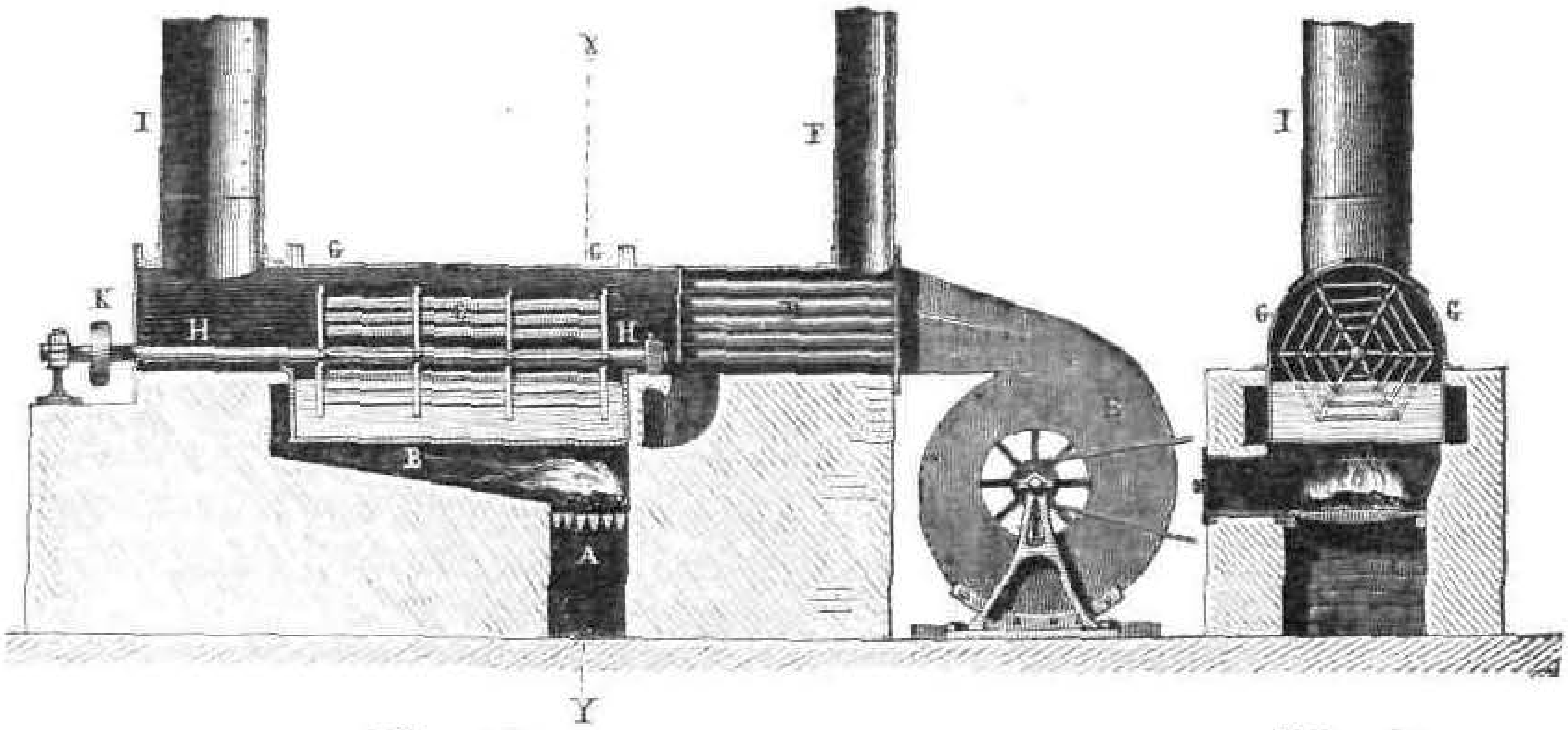


Fig. 18. Fig 19.

In the Colonies vessels of this kind have been used, but without draught; the air being brought by the draught of the furnace and circulated in the vessel around the moving drum; this drum was made of pieces of wood, fixed in three or four circles on the revolving shaft.

Circular metallic cloths in large links may also be fixed on the revolving shaft, and would constantly be saturated with fresh liquid, and which the current of air would be obliged to pass through; but this current would meet with more resistance, and the contact between the air and the liquid would only take place to a small extent.

1596. In the preceding arrangement, it would be better to facilitate cleaning the metal cloths, to have them flat and parallel, as in paragraph 1593. It would also be better to place the air tubes in a cylindrical case, the ends

of which would open into a case; those at the bottom receive the air from the ventilator, and the top ones would supply the hot air into the vessel; the smoke would circulate amongst the tubes at the upper part and flow into the chimney at the lower part; the heat of the gases would thus be better utilised. By means of these apparatus, a liquid may be evaporated rapidly by a current of air at a given temperature, by heating the liquid, or the air, or both. These arrangements would be better than that described in paragraph 1572. They would chiefly be useful for concentrating sugars, which cannot be submitted to a high temperature, without being damaged.

1597. Figure 20 represents the arrangement of another apparatus for evaporating by a current of air. A is a cylindrical vessel, closed at both ends, into which steam is admitted from the pipe *a*; *b* is a pipe for discharging the air, and *c* the condensed water pipe; the vessel is covered outside with a metal coating. The liquid to be evaporated flows continually through the pipe *d*; it runs into a cup *e*, which has small holes in the bottom, where the matters which the liquid holds in suspension, remain; from there it falls into another vessel with holes all round it, which distributes it uniformly over the metal coating; the concentrated liquid is collected in the gutter *g g*, and flows out through the pipe *h*. The cylinder A is surrounded by the cylinder B, which is both wider and higher, through which passes upwards the current of air, either

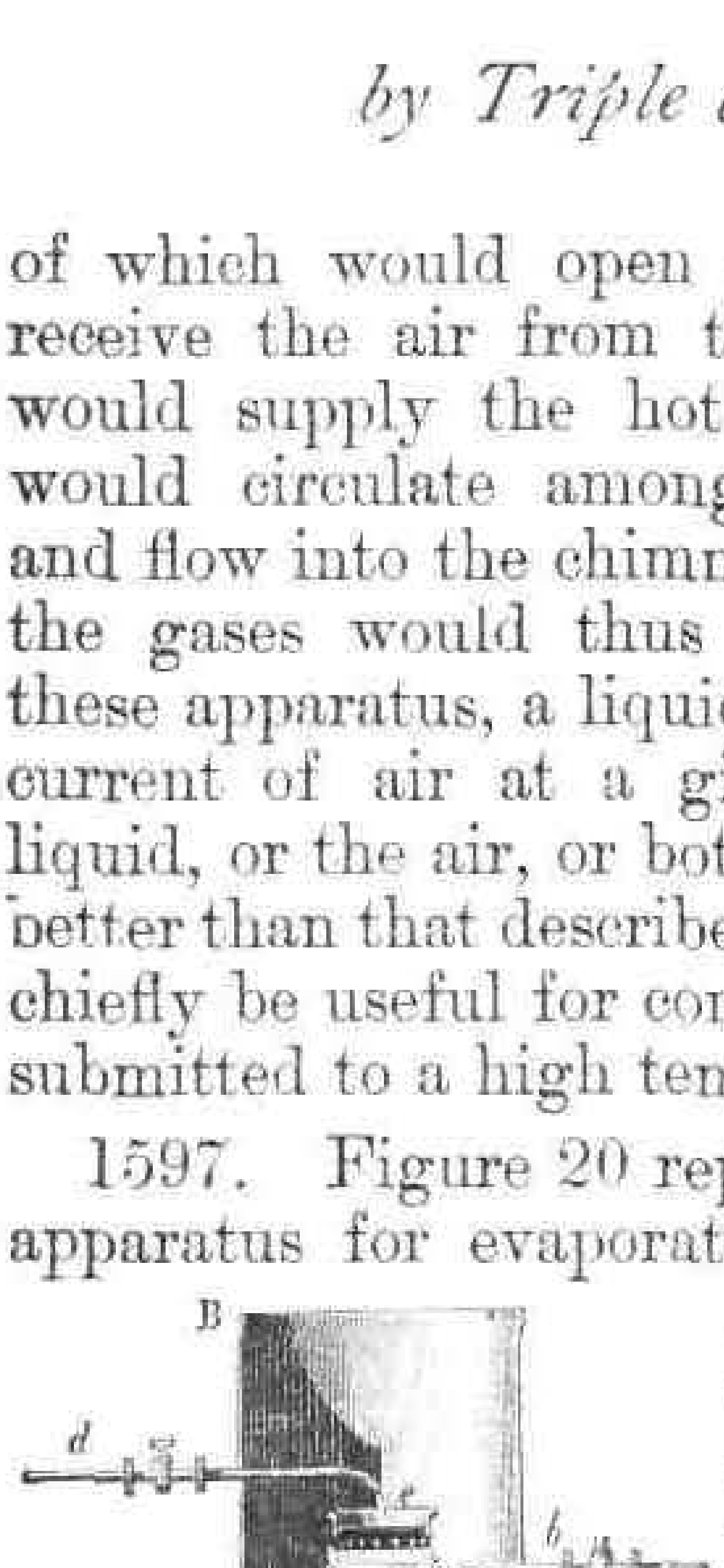


Fig. 20.

from the ventilator, or simply attracted by the heat. The annular drain, *k k*, receives the water condensed on the surface of the outer cylinder. This arrangement, intended for the concentration of syrups by the exhaust steam from the engines, has seldom been used; it has several serious drawbacks, the worst being the difficulty of cleaning it. It is evident that if the steam supplied into the cylinder A was at high pressure, the apparatus would only be of use to discharge the vapours.

CONCENTRATING BY HOT AIR INTRODUCED INTO THE LIQUID.

1598. This method of evaporation, invented in 1812 by Parmentier, is fully described in a book published in that year. The apparatus consisted of a forge bellows, the pipe from which communicated with a vessel perforated with a large number of holes, which was sunk in the liquid to be evaporated. Since then, many people have taken out patents for the same object; one of those which have been applied was Mr Brame-Chevaliér's, represented in figure 21. A A′ is a steam boiler; it contains a serpentine B B′, communicating at one end with a bellows C, and the other end is im-

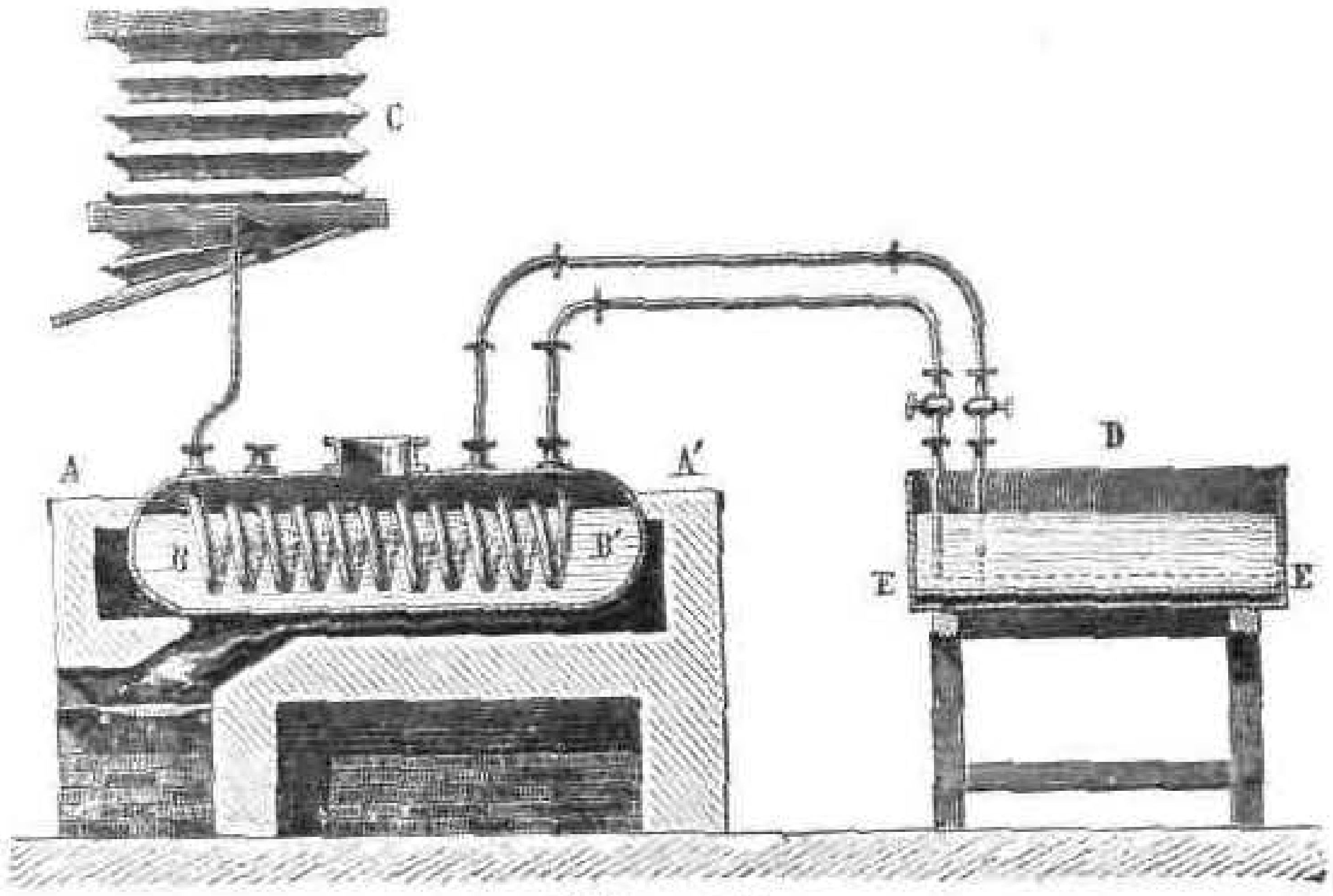


Fig. 21.

mersed to within a short distance of the bottom of the concentrating vessel D, which is fitted with a perforated plate. The boiler supplies steam into the double bottom E E.′ for the purpose of raising the temperature of the syrup. Mr Brame-Chevaliér reports the result of an experiment which he made. The vessel was charged with 50 kilos of syrup clarified to 36°, the pressure of the vapour was 1½ atmosphere, and the operation lasted 56 minutes; the temperature of syrup at the beginning was 85° and at the end 93°. In another experiment the air was passed through the syrup, and the operation was completed in 28 minutes, the temperature of the syrup changed from 70° to 72°.

Mr Brame-Chevalier has erected on a large scale an apparatus for sugar refining, and manufacturing sugar from beetroot. They consist of a blowing machine for compressing the air, an apparatus for heating it, and the

vessels for boiling to grain, in which the syrup was heated by the steam, and supplied by hot air injected into it. These apparatus, although well arranged and constructed, have completely disappeared, they are too complicated and too expensive, and consume more fuel than those which evaporate in a vacuum, and the syrup, by reason of its viscosity, retains a large quantity of air, which retards the crystallisation.

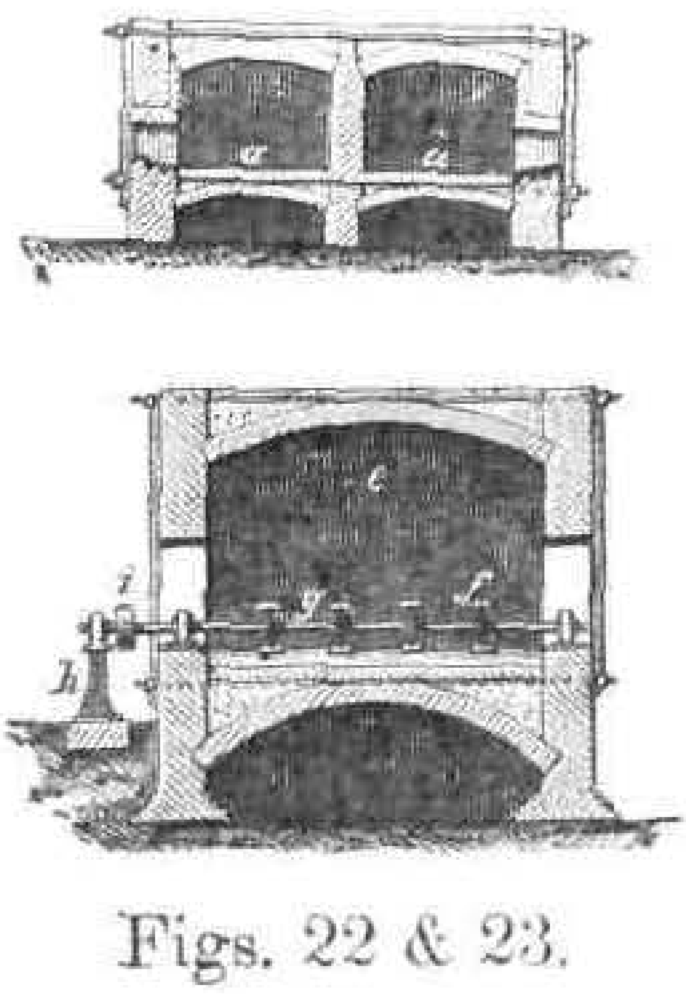
CHAPTER 5.

DIRECT EVAPORATION BY BURNT AIR.

1599. If the materials contained in the liquids should require to be calcined, direct heat from the fires is used to effect this operation, when the solutions have been brought to a suitable state of concentration; that is what is done in the manufacture of artificial carbonate of soda. To extract by evaporation, the potass which is found in the residue from the distillation of the alcoholic liquors got from the fermentation of beetroot sugar molasses, the molasses is diluted with a quantity of water, sufficient to bring the density of the liquid to about 1·060, and then is added, for every 100 kilos of molasses at 40° Baumé, 1·5 kilos of sulphuric acid at 66° and 1·5 kilos of pressed yeast. The mixture is then left to ferment at a temperature of 20°. After the distillation, the wash, on leaving the still, is submitted to evaporation in copper boilers containing serpentines supplied by steam at high pressure, until the liquid reaches 20° Baumé, after which the evaporation and calcination takes place in air furnaces. As a rule, 27 to 28 kilos of raw salt per cubic metre of wash are procured. This salt is of various compositions, according to what it has been extracted from, and which we show in the following Table:—

	Germany.	Puy-de-Dome.	Department de L'Aisne.	Department du Nord.
Carbonate of Potass - -	43·71	55·82	45·30	30·37
,, ,, Soda - - -	14·20	5·54	13·86	21·49
Chloride of Potassium - -	15·52	8·84	17·02	19·31
Sulphate of Potass - - -	8·05	14·52	8·00	10·91
Water, Coal, Insoluble Matter	18·52	15·28	15·82	17·92
	100·00	100·00	100·00	100·00

1600. The method of concentration of solutions of soda and solutions of potass could be considerably improved on the score of economising fuel, by the following arrangement, as an addition to the furnace for calcining the materials, there should be a rectangular boiler, arranged as shewn in Figures 16 and 17, the bottom of which should be a little above the fire-grate of the furnace, and the sides should be built up with masonry, so that the liquid could only be heated with the hot air which would pass into the space between the metal plates; it is evident that the burnt air could only be discharged at the temperature of the vaporisation of the liquid, and that the concentrated liquid should go direct to the reverberatory furnace. In this method, supposing 18 cubic metres of air used to burn 1 kilo of coal, the volume of gas thrown off at 100° would be 23·4cm; the heat drawn in by the air would be equal to $18 \times 1{\cdot}3 \times 0{\cdot}24 \times 100 = 561$ calories; the heat used for the evaporation would therefore be $8000 - 561 = 7439$ calories, which nearly corresponds to 11·4 kilos of water evaporated, the volume of which would be equal to $11{\cdot}4 \times 1{\cdot}7 = 19{\cdot}38$cm; therefore the total volume of air and vapour at 100° passing off by the chimney would be $23{\cdot}4 + 19{\cdot}38 = 42{\cdot}78$cm. One chimney should be sufficient for draft, and to carry off the vapour, as the mixture would be at 100°, and the density of vapour being much less than that of air under the same pressure and at the same temperature. But as the vapour produced might be in a blistered condition, caused by the cooling of the chimney, it may be feared that the draft will not be sufficient; in which case it would be prudent to produce a mechanical draft, which would not be difficult.



Figs. 22 & 23.

1601. The conditions above related will be found realised in Mr Porion's furnace for evaporating beetroot wash, and which is shown in figures 22, 23, and 24. The first represents a horizontal section of the furnaces, *a*, *a* are the incinerating furnaces, heated by coal burning on the bars *b*; these furnaces are represented in transverse section in figure 24; in *d* there are two iron plates perforated with holes, which admit a

certain quantity of air for the purpose of suppressing the black smoke from the fires; *e* is the evaporating flue, which receives the wash from L through a pipe fitted with a float cock, which regulates the supply. In this flue, which goes to the chimney *k*, there are two shafts *g*, fitted with agitators or paddles *f*; these shafts receive a rapid rotatory motion from the pulleys *i*; *j* are doors for cleaning; *o* are openings made in the arch of the flue, and are used for cleaning the sides of the flue. It is easy to imagine what takes place in the furnace; the liquid admitted on to the flue *e* forms an extended layer 0m. 20 thick, and is there submitted to a considerable evaporation, which is increased by the action of the paddles, these project into the current of hot air, carrying up the liquid, which falls in fine drops, causing an immense increase in the surface of contact of the liquid and the hot air. The wash concentrated on the flue is admitted to the furnace; when the mass takes body it should be stirred with pokers to regularise the incineration, this latter is not finished in the furnace; the raw salt being removed before it is complete, the salt is distributed in heaps, and the coal which it contains finishes by burning slowly.

We thus obtain a considerable useful effect; one of Porion's furnaces is sufficient to heat 1600 hectolitres and more of wash in 24 hours. The drawbacks brought against it are, on the one part, the mechanical drawing in of the finest drops by the currrent of air, and consequently a loss of salt; on the other part, the contact of the combustion of coal, always full of sulphurous acid, with the liquid to be heated, which causes the

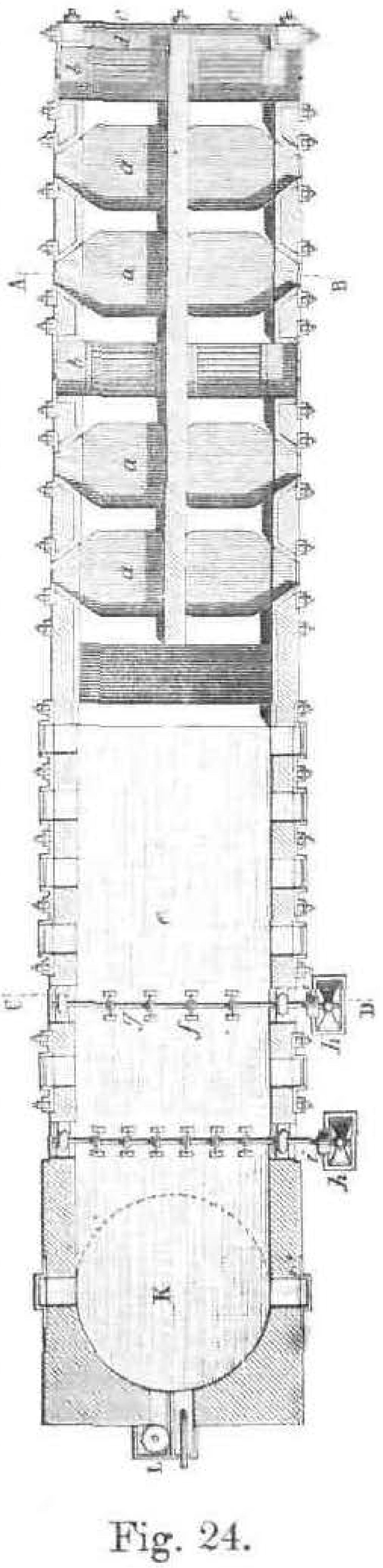


Fig. 24.

transformation of potass contained in the salts into sulphate of potass.

1602. An attempt has been made to pass the gases which leave the furnace, through the liquid to be evaporated; the boiler had a double bottom, perforated with small holes; the gas arrived at the bottom, and escaped in small streams, passing through the liquid. A very good effect of the heat produced by the fire was thus obtained; but the complication of the apparatus and the force necessary to put the air in motion, have caused this to be abandoned.

CHAPTER VI.

EVAPORATION BY STEAM.

1603. In all methods of evaporation produced by heat, we may make use of steam or vapour from any other liquid to heat the matter to be evaporated; up to the present only steam has been used. As a general rule this method does not give any economy of fuel as compared with direct heating, since, in the formation of the steam, there is as much and even a little more loss of heat than in direct heating of the liquid to be evaporated. Nevertheless, there are circumstances in which there is really a saving; that is when the evaporating apparatus are numerous, because the vapour being supplied by a single furnace, the loss of heat by the sides of one furnace is much less than that from several producing the same result. But the use of vapour is chiefly advantageous for evaporating the solutions of certain vegetable substances, which, on account of their viscosity, or the deposits formed during evaporation, may easily be damaged, when the vessels are directly exposed to the fire; this drawback cannot exist in heating by steam, because the metallic surfaces which transmit the heat can never become heated above the temperature of the steam.

1604. All the apparatus for evaporating liquids by steam are composed essentially as follows:—1st. One boiler in which the steam is formed under a pressure sufficient for its temperature to exceed by at least 15 to 20° of that at which the evaporation should take place. 2nd. One or more evaporating vessels which the steam heats, either externally by condensing in a double case, or internally by passing through an apparatus similar to the serpentines in distilling apparatus.

1605. The evaporating boilers should be constructed, as well as everything connected with them, according to the principles which have been explained, and should be heated the same as the boilers. These apparatus have generally too much resistance, and are subject to a variety of accidents, principally caused by the sudden opening of the valves for admitting the steam, producing the same effect as a violent shock; to prevent these accidents, it would perhaps be as well to fit the valves with little cogs, so as to necessitate opening them slowly.

1606. The evaporating vessels are of various forms, and the only conditions they should not be subject to are :—1st. Not to be damaged by the liquid to be evaporated. 2nd. When they are heated externally, to have a form and thickness which will enable them to resist the pressure of the vapour, which tends to deform and burst them. The condensing surfaces, as we have said, may be either outside or inside the vessels; in the first case, the surface of the vessel forms one of the sides of the channel, being the one which communicates the heat to the liquid; in the second, all the surface of the channel traversed by the steam heats the liquid.

1607. No matter how the channels in which the steam circulates are arranged, whether they are outside the vessels, or composed of tubes of different forms, bent in different shapes and placed in the vessels, they should always satisfy the following conditions :—1st, to have a thickness sufficient not to be deformed or burst by the pressure of the steam; 2nd, to be arranged in such a way as to facilitate the flow of the condensed water into an *outside receiver, or into the steam boiler*; 3rd, to have a surface sufficient to condense, in a given time, a quantity of vapour at least equal to that which the liquid under evaporation could emit.

EXAMINATION OF PHENOMENA PRODUCED IN CONDENSING APPARATUS.

1608. The phenomena produced in channels in which the steam circulates are sufficiently complicated, even when the surrounding liquid is at a constant temperature, such as when in a boiling state, and when its density does

not change. Let us first consider a pipe of small diameter, rectilineal or serpentine, but on a horizontal plane, and that the vapour enters it at three atmospheres, that is to say, about 135° at one of its extremities, and the other end is open to the air. If the pipe transmitted no heat, the vapour would expand during the progress, so that at the extremity of the pipe, it would be at the external pressure; at least that is what happens with compressed gases; there would, therefore, be a progressive increase of velocity and a cooling, resulting from the expansion, which would reduce the vapour from 135° to 100°.

Let us now suppose that the pipe is placed in a vessel containing boiling water; the transmission of the heat will condense the steam; the pressure and the temperature will go on decreasing uniformly, and the water produced by the condensation will accumulate progressively, and will be forced towards the free extremity of the pipe, and will occupy a length so much less as the velocity of the vapour is greater: this water will be discharged at 100°. If the liquid commenced to boil at a temperature above 100°, the condensed water could not take a lower temperature; consequently it would have, at its exit, a higher pressure than that of the atmosphere, and it would rapidly lose this excess of pressure, by the almost sudden production of a certain quantity of vapour. It appears from this that it would be advantageous, in respect to the useful effect of the heating surfaces, to establish a certain pressure in the receiver which collects the condensed water. If the pressure there was equal to that of the boiler, the temperature and the pressure of the vapour would remain the same throughout the extent of the pipe; but the condensed waters would not flow out. It is evidently always necessary that the pressure of the boiler should be higher than that in the receiver, so that the condensed water can be drawn in; a very small difference would suffice. In an experiment, which we will report later on, they condensed in a serpentine 250 kilos of water in 11 minutes; that is to say $\frac{250}{660}=0{\cdot}379$ kilos per second; the vapour entered at 135°, and the liquid outside was at 100°; the pipe having an inside diameter of 0m. 02, equal to an area of 0·000314 sq. metres; therefore, the water condensed per second occupied in the pipe a length of 1m. 21; and for the discharge of this water, it required an excess of pressure in water of about 0m. 10, which is only a mere fraction of

atmosphere, and which might result from the angle of the pipe. It would therefore be advantageous in respect to the quantity of heat transmitted by the pipe to have in the condensed steam receiver a pressure slightly below that in the boiler; but this advantage would not really effect anything but the efficacious part of the pipe; that is to say, that part where there is no condensed water; if the pipe was too long for the uncondensed steam to arrive at its extremity, this would only shorten the efficacious part of the pipe; these are generally of an excessive length, which makes this arrangement useless. Nevertheless, it is always advantageous to discharge the condensed water into a closed receiver, with a valve at the lower part, which opens by means of a float when the water level has attained a certain height; the pressure in this receiver should always be equal at least to the pressure corresponding to the boiling temperature of the liquid to be evaporated, and a large quantity of the heat should be utilised, if, by an excess of pressure in the steam boiler, the pipe did not condense all the vapour which was inside it.

1609. Suppose the steam, instead of going through a long pipe of small diameter, and bent in various ways, goes into an enlarged space, the surface of which may be either partially or totally covered by the liquid to be evaporated; the latter is the case where vessels with double bottoms are used, in which space the vapour circulates; the former would happen if the steam was supplied to a vessel immersed in the liquid to be evaporated; in all cases the condensing vessel should be provided at the bottom with a pipe to allow the condensed water to be drawn out. In the double bottom arrangement, the condensing surface does not change, it is always equal to the surface in contact on one side with the steam, and on the other with the liquid to be evaporated; according to this, it seems to be more favourable to the transmission of heat, than the pipes in which the flow of the condensed water reduces the area of the efficacious surfaces; but, in general, the contrary is the case; the double bottoms of the vessels produce much less effect, under the same conditions, than the same surface in pipes of small diameter. This difference may arise from several causes; from an expansion of steam resulting from its entering into a large space; or from the fact that the air has not been completely discharged from the space; or lastly, that the layer of water

which covers the condensing surface is not renewed so rapidly as in the pipes. These various causes may perhaps be at work simultaneously. It is very probable that it is to the presence of molecules of air mixed with the steam that we should principally attribute the inferiority generally observed in apparatus with double bottoms, compared to those with pipes. In all cases, there is no doubt that there is a great advantage in discharging the air as completely as possible from condensing vessels, by admitting a certain volume of steam, and establishing nearly the same pressure as that of the boiler in the condensed water receivers, or *at least to arrange this receiver in such a way that the* steam there receives a pressure greater by some degrees than that which corresponds to the temperature of the boiling liquid.

1610. Whatever the arrangement of the condensing apparatus may be, it is always observed that, for the same excess of temperature, the quantity of steam condensed increases with the temperature of the liquid, and that it is much larger when the liquid is boiling than when it is *being heated ; this increase in the quantity of heat* transmitted arises without doubt, from the fact that the liquid which comes in contact with the metal renews itself more rapidly as it becomes hotter, and with a still greater rapidity when it attains boiling point.

EFFECTS PRODUCED BY HEATING SURFACES.

1611. We have seen that the quantity of heat which can be transmitted by a copper plate 1 metre thick, the two surfaces of which are maintained at a constant temperature, is equal to 69 calories per square metre per hour, for a difference of temperature of 1°, which corresponds, for a thickness of 0m. 001, to the condensation of $\frac{69000}{650} = 103$ kilos of steam per square metre per hour. But to obtain such a result it would be necessary that the *liquid which comes in contact with the two surfaces should* be renewed with a much greater rapidity than that produced naturally; that is the reason why the quantity of heat transmitted by such apparatus as we are now considering, is much less.

1612. According to Clément-Désormes, one square metre of thin copper, exposed on one side to steam at 100°, and on the other side to water at a mean temperature of 28°, condenses per hour 100 kilos of steam, which is equal to a condensation of $\frac{100}{72} = 1 \cdot 4$ kilos per square metre per hour per degree of difference of temperature. Clément has not described the apparatus which he used; but, presumably, he operated with those with double bottoms; he did not take the necessary precautions to discharge the air, and the liquid was not brought to boiling point, all of which would reduce the transmission of heat considerably.

1613. A cylindrical double-bottomed vessel, which contained 900 kilos of beetroot juice, at a temperature of 4°, was heated by steam to 135°, the liquid was brought to boiling point in 16 minutes, which corresponds to $\frac{900 \times 96 \times 60}{16} = 324 \cdot 000$ units of heat per hour, for a mean difference of temperature of 83°; and as the surface of the double bottom had 2·40 square metres this quantity of heat corresponds to the condensation of $\frac{324 \cdot 000}{650 \times 2 \cdot 4} = 208$ kilos of steam per square metre per hour for a difference of temperature of 83°, or 2·50 kilos for a difference of temperature of 1°, which is much larger than that given by Clément. In this apparatus the steam supply pipe was 0m. 04 in diameter, and there was an air escape cock fitted to the upper part of the double bottom.

1614. In apparatus formed of a single pipe of small diameter, the condensation of the vapour is much greater. Here follow the results of several experiments made by Messrs. Thomas and Laurens, on an evaporating pan heated by steam which circulated through a pipe.

The pipe was 42 metres long, 0·034 metres outside diameter, and had 4·48 square metres of heating surface, 400 kilos of water at 8° was admitted into the vessel; steam was supplied into the serpentine at a mean pressure of three atmospheres and at 135°. In four minutes the water boiled, in fifteen minutes 250 kilos of water were evaporated. In the first part of the experiment, 400 kilos of water were heated in four minutes from 8° to 100°, and consequently received $400 \times 92 = 36800$ calories, corresponding to $\frac{36800}{650} = 56 \cdot 6$ kilos of water evaporated in 4

minutes, we could therefore condense $56{\cdot}6 \times 1{\cdot}5 = 84{\cdot}9$ kilos of steam per hour, for an excess of temperature of $135^\circ - \frac{108}{2} = 81^\circ$, and for a difference of 1° it would only be $\frac{849}{81} = 10{\cdot}48$. As the heating surface was 4·48 sq. metres, the quantity of vapour corresponding to the heat transmitted per square metre per hour and per degree of difference of temperature, was only $\frac{10{\cdot}48}{4{\cdot}48} = 2{\cdot}33$ kilos. It is necessary to note that the serpentine and the pan were heated at the same time. In the second part of the experiment, in 11 minutes, for a difference of temperature of 35°, a surface of 4·48 sq. metres evaporated 250 kilos of water, which gives 8·70 kilos of vapour condensed per square metre per hour and per degree of excess of temperature.

In another experiment, there were two serpentines; each 15 metres long and 0·034 metres outside diameter, having a united heating surface of 3·67 square metres. The steam in the serpentines being at a pressure of 2 atmospheres and 121°, 60 kilos of water were evaporated in *five minutes*, which is equal to 196 kilos per square metre per hour, for a difference of temperature of 21°, or nearly 9·34 kilos per degree of difference of temperature.

1615. Mr Walkhoff gives, as the results of his experiments with serpentines, 112 kilos of steam condensed per square metre per hour for a difference of 37°·7, or $\frac{112}{37} = 3$ kilos per degree of excess.

1616. Mr P. Havrez, mining engineer in Belgium, made, on the same subject a number of experiments published in Mr Cuyper's Revue Universelle, Vol. XX.

In a first series of experiments, a copper serpentine of 0·04m. diameter, making three coils of 0·46m. diameter, with a heating surface of 0·544 square metres, was placed in an iron vessel containing 100 kilos of water, the initial temperature of the water being 20°, that of the steam 149°, the water was made to boil, condensing 207 kilos of vapour per square metre per hour, equal to 2·32 kilos of steam condensed per degree of mean excess. In a second experiment the initial temperature of the water was 20°, and that of the steam 152°, he condensed 120 kilos per square metre per hour to bring it to boiling point, or

$\frac{220}{92}=2{\cdot}39$ kilos per degree of mean excess; lastly, the initial temperature of the water was 40°, and that of the steam 152°, the quantity condensed per square metre per hour to boil the water was 190 kilos, or $\frac{190}{82}=2{\cdot}32$ kilos per degree of mean excess. 50 to 79 kilos of steam per square metre per hour were expended to maintain the water at boiling point, or 1 to 1·6 kilos of steam was condensed per degree of mean excess.

In a second series of experiments, Mr Havrez operated with a double-bottomed iron vessel, the heating surface of which was 0·611 square metres. Using steam at 149°, he heated the water from 20° to 100°, condensing 69 kilos of steam per square metre per hour, or 0·77 kilos per degree of mean excess. About the same quantity of steam was required to keep it at boiling point.

1617. The following appear to be the results of what we have stated—

1st—That, with copper double bottomed vessels, before boiling point is reached, the quantity of steam condensed per square metre per hour and per degree of excess of temperature, is equal to 1·4 kilos for a mean excess of temperature of 28°, and 2·57 kilos for a mean excess of 83°; the difference probably results from the fact that the liquid is more rapidly renewed when it becomes hotter; with iron vessels, according to Mr. Havrez, the transmission would be much less.

2nd.—That with serpentines, during the heating of the liquid, the quantity of heat transmitted per hour per square metre and per degree of difference of temperature, was *2·33 kilos* whilst heating, and *8·70* to *9·33 kilos* whilst boiling; the great difference observed in these two cases results doubtless from the rapid renewal of the liquid which comes in contact with the tubes during boiling. The first quantity 2·33 kilos is probably too little, caused by the heat necessary to heat the apparatus, which has not been taken into account. The second quantity, 8·70 to 9·33 kilos, is probably a maximum rarely attained in practice, the quantity found by Mr. Havrez, viz.: 1 to 1·6 kilos being a minimum.

1618. To summarise, we may admit, with double bottoms of copper, a condensation of $2\frac{1}{2}$ kilos of steam per square metre per hour and per degree of difference of

temperature, during the time the liquid is being brought to boiling point; but we know nothing exact about the *quantity of steam condensed after boiling point is reached.* With double bottoms of iron, the condensation would not rise to 1 kilogram. With pipes it will be at least 2⅓ kilos during the heating of the liquid, and at most 8 to 9 kilos after it is heated. But with serpentines there is one important condition, their length must not exceed a *certain limit, as the steam does not necessarily reach the* far end, if the length is too great it is almost certain that the steam will expand if one of the extremities is open to the air. It has been proved by experience that serpentines of 25 to 30 millimetres interior diameter, should not be longer than 30 to 40 metres. It is important to note that *the quantity of steam condensed per square metre per hour* and per degree of difference of temperature having been found to be the same in vessels with double bottoms and in pipes, it is very probable that it would be the same after boiling point is reached, but all precautions should have been taken to entirely discharge the air.

Other heating apparatus are also used in which the steam circulates simultaneously through several pipes, known by the name of grates; in these apparatus we are *not certain* that the steam circulates simultaneously through all the pipes, so that it is impossible to state positively the effect produced; however, if all the pipes were lead into another of larger diameter, it would seem probable that all were working, and then the heating surface ought to produce the same effect as if the steam flowed through a single pipe.

1619. *In the preceding paragraphs we have taken, for the excess of temperature of the transmitting surfaces,* the difference between the temperature of the steam in the vessel and that of the liquid; it is a useful method in practice, but the difference of temperature of the two surfaces is really smaller. At first the exterior surface is at a higher temperature than that of boiling liquid, as it is *only on this condition that there is transmission of heat;* and the other surface is at a lower temperature than that of the steam in the vessel, because the steam has experienced a certain amount of expansion in its course, and the condensation of the steam is not effected on the metallic surface, but on a layer of water of a certain thickness, which constantly covers the metal.

1620. In order to give an idea of the method to be used to calculate the quantity of heating vapour to be produced, and the area of the heating surface of an apparatus, we will take as an example the concentration of sugar syrup. The syrup, before boiling to grain, is called cleare, and is usually composed of 30 parts of water and 70 of sugar. To be brought to 47° of the areometer, which is the usual degree of concentration, it should lose about 15% of water. Therefore, if it was wished to concentrate per hour 10,000 kilos of cleare, it would be necessary to evaporate 1,500 kilos of water, and raise the mass to boiling point. Supposing the steam was at 3 atmospheres, and 135°, and the cleare at 20°, as the specific heat of the cleare is half of that of the water, the quantity of heat necessary to heat the mass to 110°, which is about boiling point, will be $\frac{10000 \times 90}{2} = 450{,}000°$, corresponding to 818·1 kilos of steam; therefore, the total quantity of steam to be supplied per hour will be $1500 + 818{\cdot}1$ kilos $= 2318{\cdot}1$ kilos. As to the area of the heating surface, it is necessary to remember that, during the heating of the cleare, the mean difference of temperature between the steam and liquid is $135 - \frac{110+20}{2} = 70°$, whilst the mean excess of the temperature of the vapour over that of the cleare, during evaporation, is only 21°. You can therefore see that, in respect to time, everything takes place the same as if we were condensing $1500 + \frac{21}{70}\ 818$ kilos$=1745{\cdot}4$ kilos per hour, with a difference of temperature of 21°. The extent of the heating surface, supposing the steam to be circulated in serpentines, should be $\frac{1745{\cdot}4}{21{\cdot}8} = 10{\cdot}4$

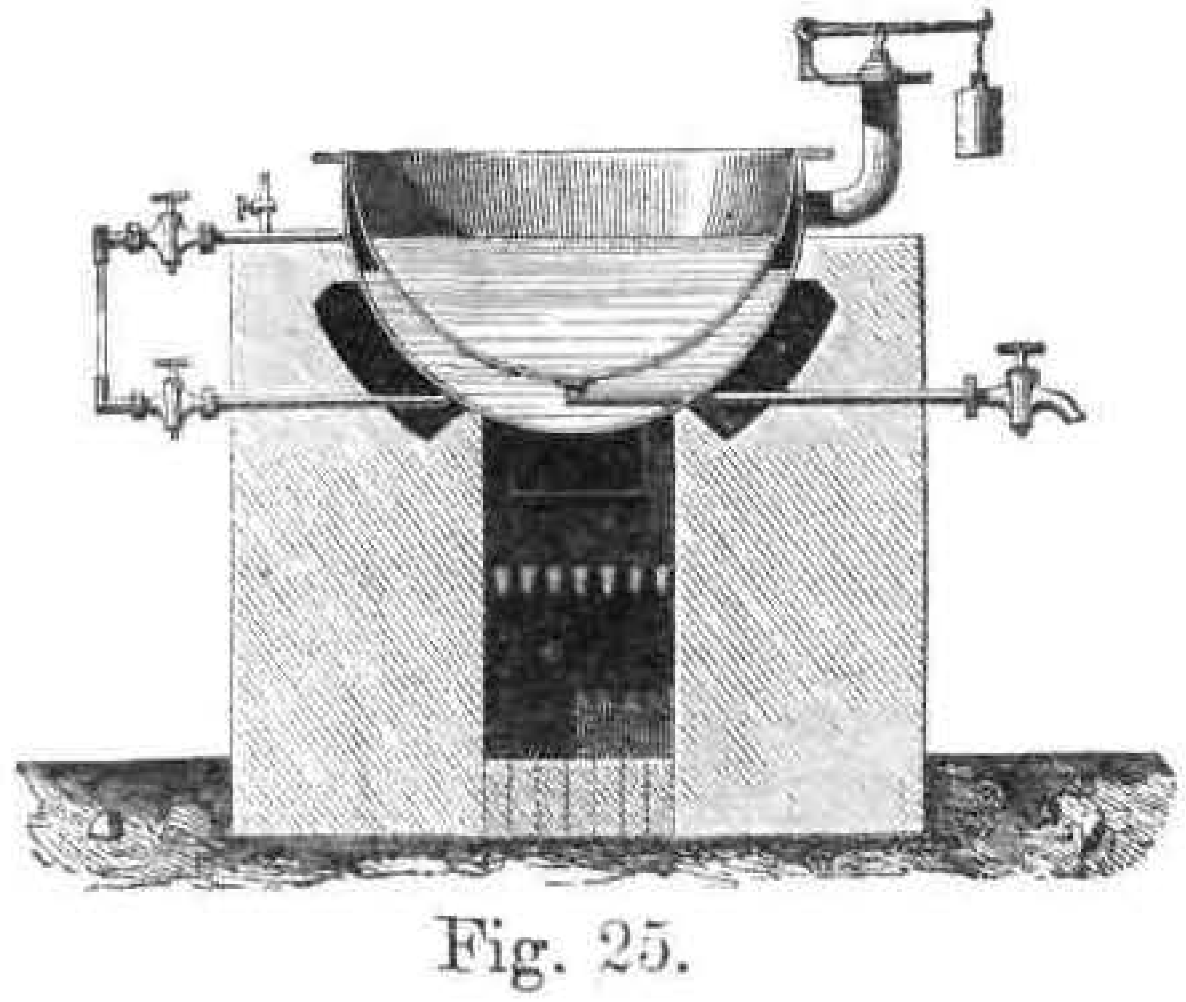


Fig. 25.

square metres. According to what we have already said it will be necessary to have three or four apparatus.

We will now examine the different arrangements which have been adopted.

1621. The apparatus represented in Fig. 25 is the most simple that can be used for heating and evaporating by steam; it consists of two boilers placed one inside the other, the flanges of which are held by bolts, water is put into the space which separates them, and the liquid to be evaporated into the inside vessel. There is a safety valve to prevent the pressure of the vapour exceeding the limit fixed; a gauge indicates the level of the water in the double bottom, another pipe fitted with a cock and a funnel admits the water into the double bottom at the commencement, and to replace that which may escape as steam by the safety valve; the concentrated liquid flows off through a pipe fitted with a cock. The apparatus is erected on a furnace which directly heats the outer boiler.

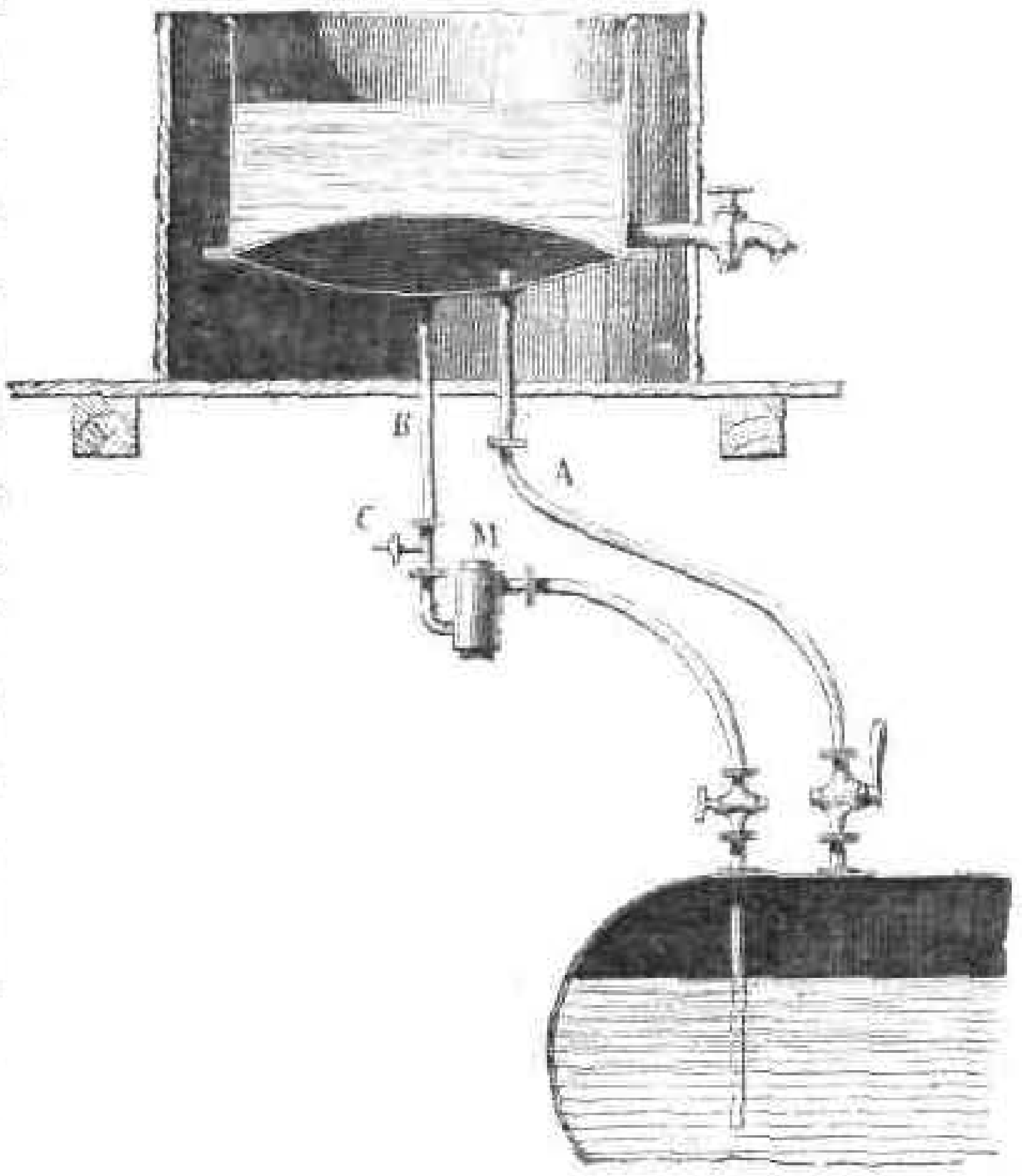


Fig. 26.

1622. Evaporating vessels are often given the forms shewn in Figs. 26, 27, and 28, in which A represents the pipe which supplies the steam from the boiler; B, the

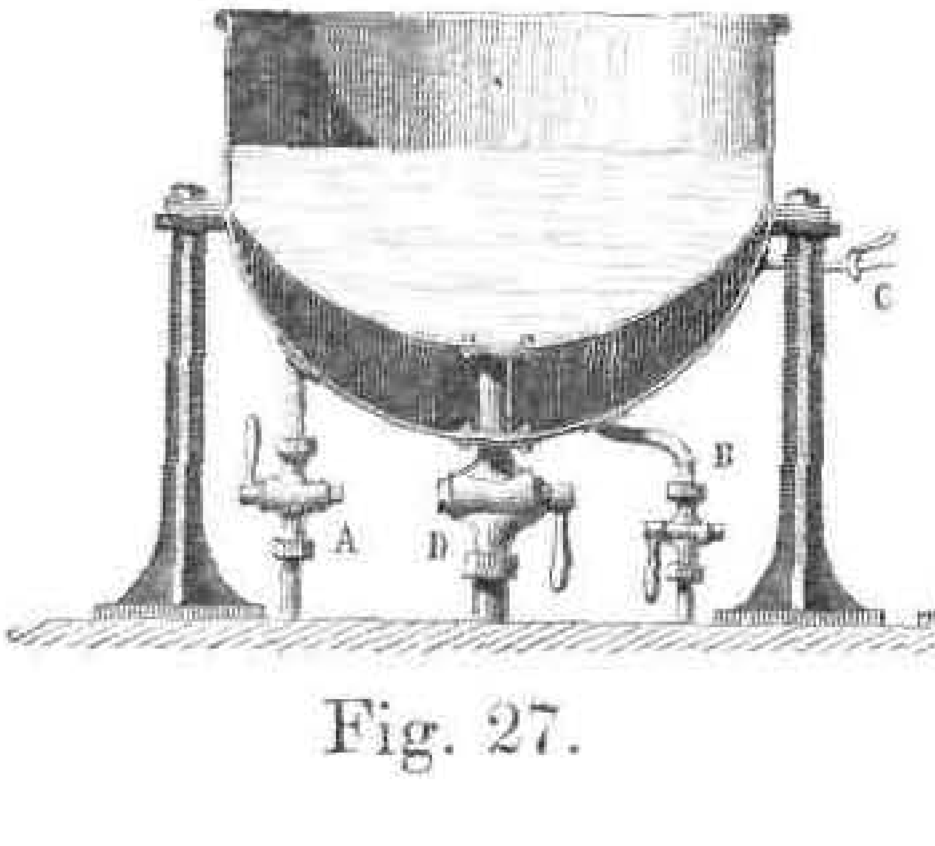


Fig. 27.

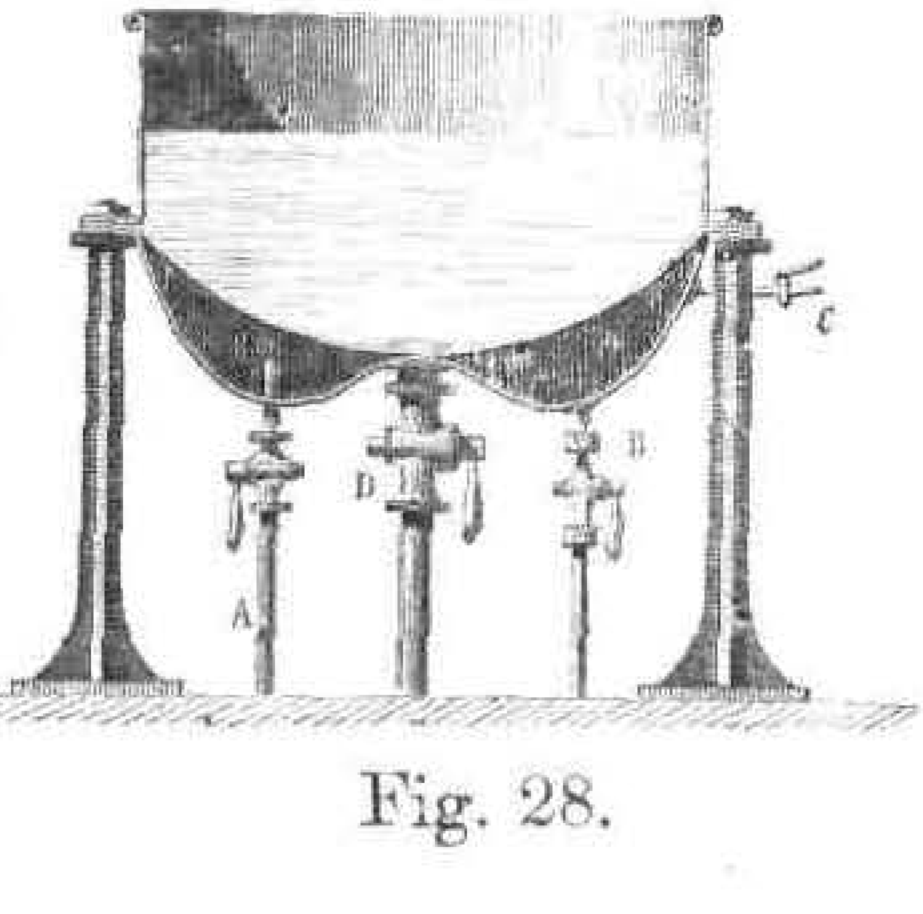


Fig. 28.

condensed water outlet pipe ; C, the air pipe ; and D, the pipe for carrying away the concentrated liquid. The first arrangement (Fig. 26) has the advantage of having this latter pipe placed laterally. In the last, it is better placed than in Fig. 27, in which it is difficult to make tight.

1623. It is possible to place the evaporating vessel above the steam boiler, and allow the steam and the water to flow through the same channel; although this arrangement is very simple, it is rarely used, as it requires the common channel to be of large diameter and rise in a continuous manner, and as the movements of the water and the vapour are in opposite directions which always causes annoyance.

1624. The condensed water is often returned direct to the steam boiler through a separate pipe, which descends to the bottom of the boiler, to prevent the water from the boiler being raised into the space where the steam is condensed, the pipe is fitted with a box, containing a valve, which opens by the pressure from below. The pressure of the steam keeps it closed; it only opens when the weight of the column of condensed water, increased by the pressure remaining in the condensing chamber, exceeds the pressure in the boiler; the water, after having filled that portion of the pipe above the valve, accumulates in the chamber, it reduces the condensation by reducing the area of surface on which it operates, and consequently increases the elastic force of the steam in the chamber. In the most unfavourable case, the condensed water would necessarily escape after each operation, when the vessel required to be emptied; sometimes it is received into a closed vessel, of which we will speak later on.

1625. A number of inventions have been made to increase the condensing surfaces and to facilitate the discharge of the air from the chambers, which will now be described successively.

At first a cluster of tubes of equal size and parallel was used, a few centimetres in diameter, fixed at each end to two pipes of larger diameter; one of them was divided by a transverse partition into two equal parts; through one of these pipes, the steam goes through half of the tubes, and returns through the other half; this arrangement has several drawbacks; 1st. The steam rarely circulates in all the tubes, consequently the air is never

completely discharged, and a portion of the heating surface is lost. 2nd. The unequal expansion of the tubes, which remain full of air, and of those in which the steam circulates, often causes the soldering to give way. 3rd. the vessel can only be cleaned by disconnecting the flanges to which the grate is bolted.

The arrangements invented by Pecqueur and Moulfarine to allow each of the tubes to expand independently, have been completely abandoned. The most simple of all these apparatus is a tube bent in a coil (fig. 29), and it is also the most generally used. In it the air can be completely discharged, and the variations of temperature of its different parts are without influence. In the vessels for concentrating or boiling the juices, in which these serpentines are used, it is not uncommon to find two of these *one above the other*. The steam moving in opposite directions in the two serpentines, makes the temperature uniform.

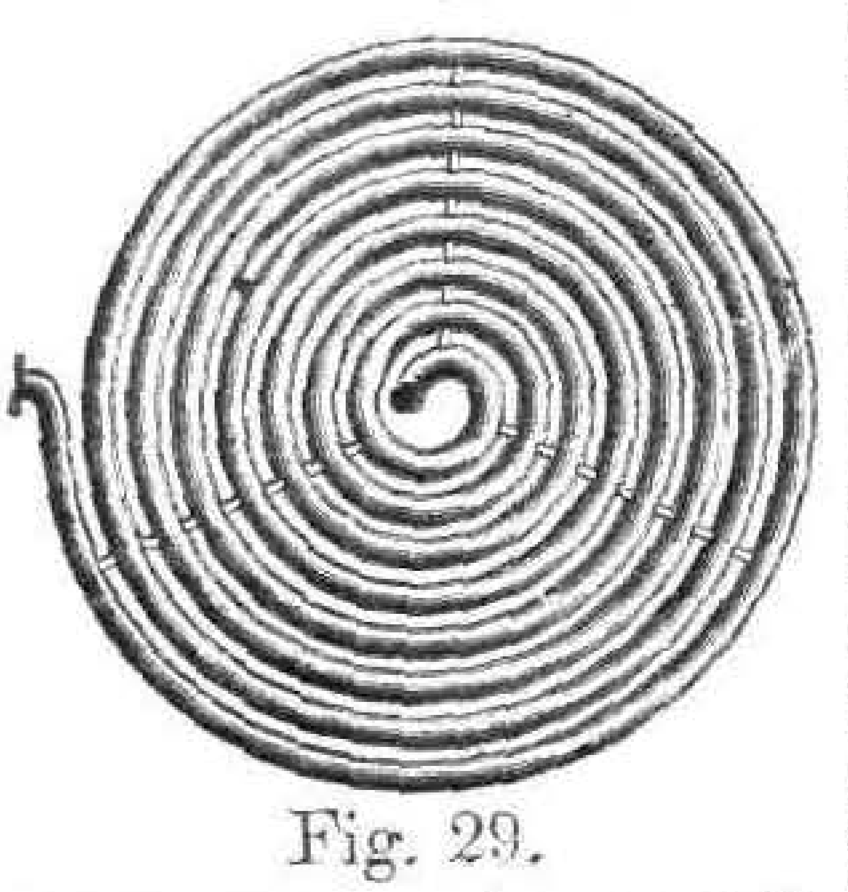


Fig. 29.

1626. In all the apparatus of which we have been speaking, when the condensed water is not discharged direct it is important to use a closed condensed water receiver which maintains the steam at a certain pressure and does not allow any of it to escape. These receivers are represented in Figs. 30 and 31; in the first, the vessel A receives the condensed water by the pipe B, and the opening C, at the bottom is closed by a conical plug; this plug can be raised by a rod which passes through a stuffing box at the top of the vessel. It is fitted with a gauge pipe, safety valve and steam gauge, all that takes place can thus be seen, and the vessel emptied when full; the water runs out into the tanks for supplying the boiler.

Figure 31 represents a similar arrangement, the difference being that the plug which closes the orifice at the bottom is worked by the float F, the gauge pipe is therefore not required.

1627. Several other inventions have been made for evaporating solutions of sugar, chiefly with a view to shortening the duration of the concentration. Before

noticing them I will recall some of the principles which should always be useful in arranging these apparatus.

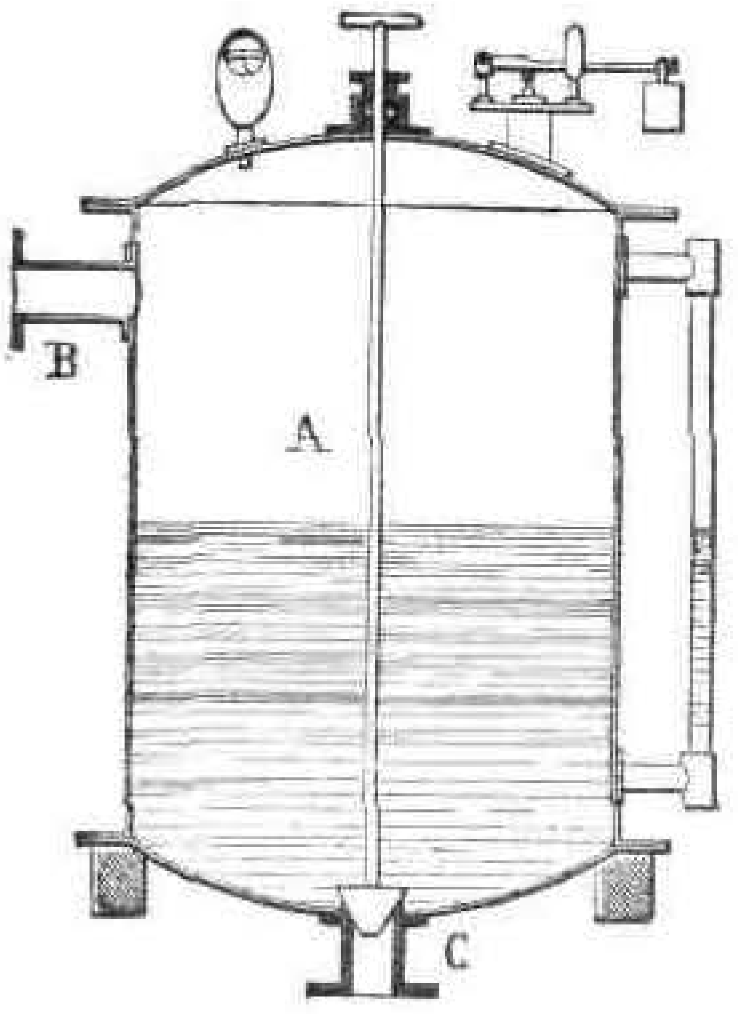


Fig. 30.

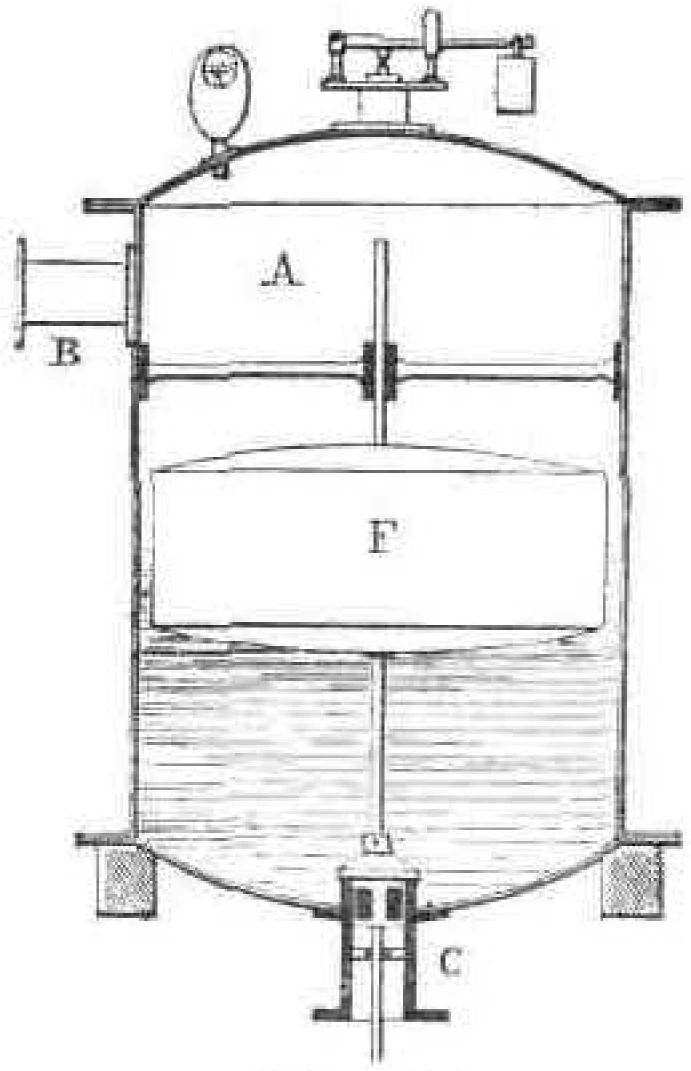


Fig. 31.

1628. When evaporation is caused by boiling, the quantity of vapour produced represents the quantity of heat transmitted to the mass of liquid, provided the free surface of the liquid is not of too large an area, as this would cause a quantity of heat to be lost by radiation and contact with the air. It should be the same in evaporation as it has been proved to be in the case of drying stuffs put in contact with metallic surfaces heated by steam; the quantity of vapour condensed always considerably exceeds the quantity of water which comes out of the cloth, in fact, the exterior surface is not always damped, as in the case of evaporation, but part at least, of the stated effect should be produced. Therefore, when evaporation is brought about by boiling, the quantity of vapour produced on the heating surface depends upon the area of it, and excess of temperature, this vapour would be entirely thrown off if the surface of the liquid lost no heat by radiation or by contact with the air, the result of which is a certain loss, in ordinary apparatus this loss is only slight, but it might become very great if, in the different evaporating vessels which we have described, the tubes instead of being fastened together, were spread over a large surface.

1629. When evaporation takes place at lower than boiling point, it is produced by the movement of the air, and it increases with the area of surface exposed to the air, with the temperature of the liquid and the velocity of

the current. For a certain area of surface for transmitting heat to the liquid, and of wet surface exposed to the air, evaporation can always be produced at a fixed temperature, by varying the velocity of the current. In this case, the quantity of heat absorbed for the evaporation of 1 kilo of water would be greater than when evaporation takes place at boiling point, on account of the heat lost by the radiation of the surfaces exposed to the air, and the heat used for heating the air, but this would be less as the temperature becomes higher. If it was an absolute necessity, or even an advantage, in respect to the quality of the products, to evaporate a liquid by air, the arrangements, figures 16, 17, 18, and 19, would certainly be advantageous, because, the outer case being at the temperature of the liquid, there would be no loss of heat by radiation, and the loss from the cooling of the dome could be overcome by covering it with non-conducting material; but it would be necessary to find out by experiments the influence which the rapid renewing of the air might have on the quality of the products, and to make sure that it did not produce a phenomenon similar to what was proved by passing the air through the liquid (paragraph 1598), and further, if there would not be a quantity of water drawn in mechanically.

MR. LAMBECK'S EVAPORATING CONE.

1630. This apparatus, represented in vertical section (fig. 32), consists of two vertical concentric truncated cones, A A, B B, 4 to 5 metres high; the annular space which separates them is closed at the top and at the bottom, and filled with steam coming from a boiler or non-condensing machine. The interior cone is fitted with nine conical drums *d*, toothed underneath and fixed to the same rod C C, so that they can be removed together to be cleaned. The outer cone is also fitted with nine conical drums *e*, arranged inversely to the others, and toothed on the top. The liquid to be evaporated is supplied from a reservoir F, the level of which is maintained by a float cock *a*; it is led from there through the pipe E into the vessel D, which distributes it on to the surface of the interior cone through a number of openings, and through the pipe G into the annular vessel H, which distributes it over the exterior cone. This vessel H is fitted with a number of cocks $r\ r^1$, to regulate the supply to the surface of the

cone. The two cocks *b* and *c*, regulate the distribution of the liquid into the two vessels D and H; they act in concert and are worked by two rods *f* and *f'*, fixed to the points of a moveable needle on the dial L. The liquid is uniformly apportioned, by means of the two series of cones *d* and *e*, over the interior and exterior surfaces which the vapour heats; and if it was not kept boiling, the activity of the evaporation would be increased by the upward motion of the mixture of air and vapours. The liquid concentrated on the outer surface is received by the vessel M, and falls through the pipe O, runs along the gutter I, into the tank K, in which the liquid, concentrated on the inner surface, is also received.

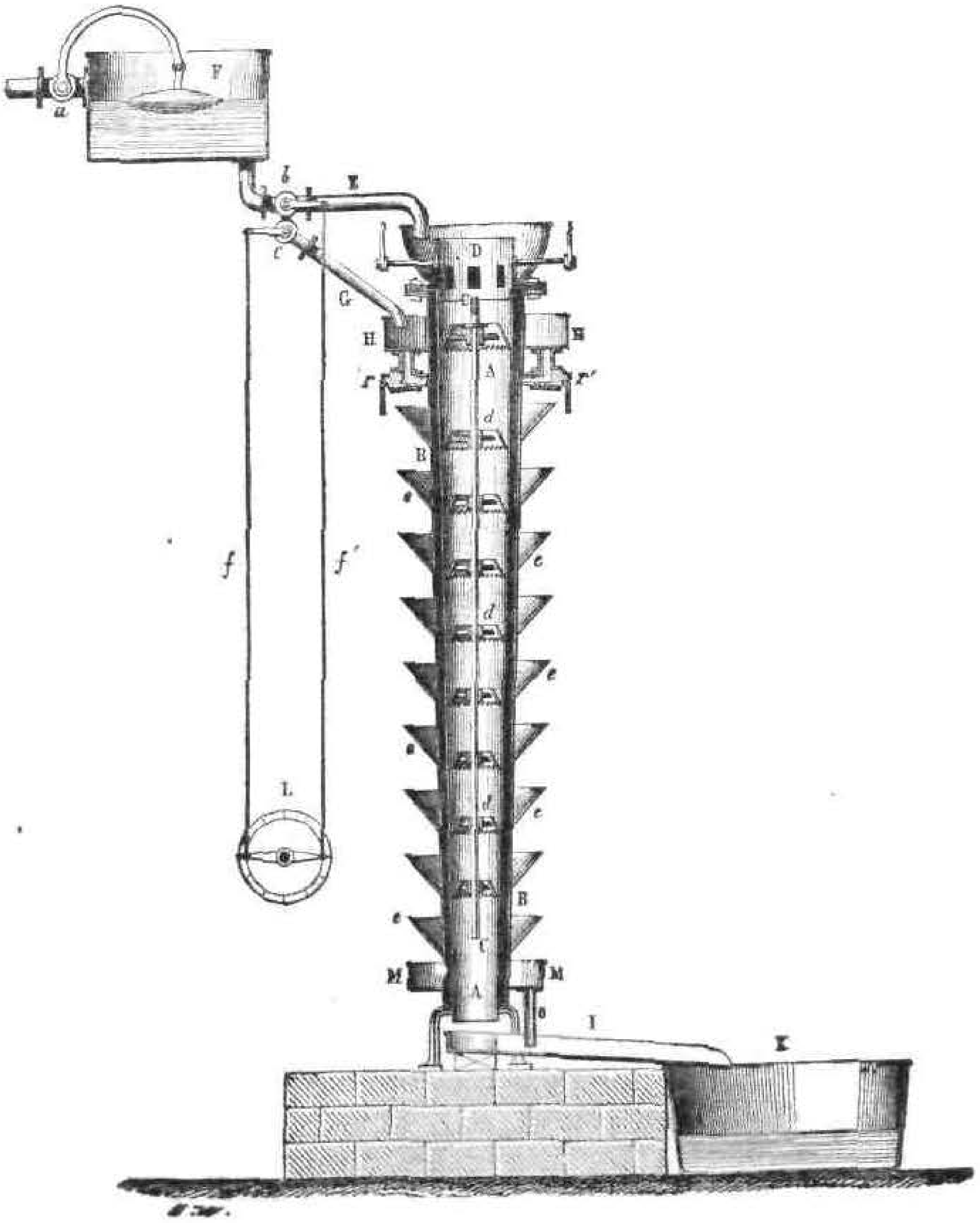


Fig. 32.

This apparatus is based on the same principle as that described in paragraph 1597, and has been adopted in several sugar factories with good results, but the quantity of steam condensed in the space between the two cones has not been calculated, and it is the relation of this quantity of steam to that which has disappeared by the evaporation which should have decided its success. I am convinced that, if these experiments had been made, they would have found a great difference between the quantities of vapour condensed on the inner surface, and that produced by the outer surface, and that the same heating surfaces, either in a double bottom or serpentine in ordinary vessels produced a much better effect. Therefore it is only useful for high pressure steam.

1631. Another arrangement for the concentration of solutions of sugar was shown at the Universal Exhibition of 1855. This apparatus consisted of a vertical copper cylinder, open at both ends, 3 metres in height and 0·5 metres in diameter, containing a serpentine of 0·03 metres diameter, which is bent on a cylinder of 0·25 metres diameter, and heated by high pressure steam. The large cylinder contained a number of hollow copper balls, held by a grating fixed at the lower part. At the upper part of the cylinder there is a tank for the liquid to be concentrated; it is perforated with a number of small orifices for the purpose of spreading the liquid over the whole cylinder, and falls on to the surfaces of the balls and cylinder. The inventor claimed that his apparatus had been tried in sugar refineries with good results, and that it would be a great advantage to sugar factories in this country (France.) But we are convinced that this is an illusion, as the principle of this apparatus is opposed to all observed laws. If the cylinder only contained the serpentine, and the liquid ran over the whole of its surface, we should be in the same position as with the apparatus which we have just described, only the vapours condensed on the inner surface of the cylinder would furnish water which, by mixing with the concentrated liquid on the surface of the serpentine, would reduce the effect produced by the latter. If we now suppose the liquid flows over the whole of the surfaces of the serpentine and balls, the liquid which covers the spheres would only get heated by the condensation of the vapours produced on the serpentine, and these balls, which are of costly construction, will only have a negative effect,

at the same time there will be a certain quantity of liquid evaporated by the current of air in the apparatus. The balls would be useful if the evaporation could be entirely done by the air, but it would be necessary to supply the liquid hot, and there would have to be a chimney sufficiently large to cause a good draught, or else the air would have to be set in motion by a machine, and in this case, the heat being supplied by the liquid itself, only about $\frac{1}{8}$th of it could be evaporated.

1632. It has also been proposed to place over a boiler a copper tube, supplied with steam, in the form of a spiral round a horizontal rotating axis; the spiral dips into the liquid, and the part exposed to the air produces a fairly rapid evaporation of the liquid, which is constantly renewing itself. It is evident that if the evaporation in this apparatus takes place at boiling point the effect would be the same if the tube was fixed and dipped in the liquid, and that if the evaporation took place at a lower temperature, it will be produced by the air; therefore the apparatus mentioned in paragraphs Nos. 1593 and 1595 would be preferred.

EVAPORATION BY THE EXHAUST STEAM FROM HIGH-PRESSURE ENGINES.

1633. The exhaust steam from a non-condensing engine contains sensibly the same quantity of heat as at its entry, and can be used to produce evaporation in the same way as direct steam, with the only difference that the liquid to be evaporated cannot be brought to 100°.

In this case air is brought in to facilitate avaporation. As an application of this system, we can quote Lambeck's evaporating cone, and the apparatus described in paragraphs Nos. 1597, 1593, and 1595, without the furnaces, and adding double bottoms to the vessels. This type of apparatus has been frequently used in the Colonies and in the French sugar factories; it has now been given up and substituted by an apparatus for evaporating in vacuo, which we will consider in the next chapter. With some slight modifications, however, they could be used for evaporating water containing sea salt.

EVAPORATION BY HEAT FROM THE CONDENSED WATER OF THE ENGINE.

1634. The heat represents more than 0·60 of the heat produced in the furnace, (well-arranged steam boilers will generate nearly 7 kilos of steam per kilo of coal) which could easily be made to evaporate liquids with the aid of contact with air. It would first be necessary to make this heat pass into the liquid to be evaporated, by heating it to the highest possible temperature. To do this, the hot water must pass through a tube, surrounded by another of larger diameter, in which the liquid to be evaporated should flow in the opposite direction. It is evident that if the caloric capacity of the liquid only differed a few units, and if the tubes were sufficiently long, or if the two movements were slow enough, there would be a complete exchange of temperature between two equal weights of water and of liquid; if the caloric capacity of the liquid was much greater or less, the weights of the two liquids should be inversely proportional to their caloric capacities. This exchange of temperature could also be effected by the aid of various arrangements, which we will treat of later, in the subject of cooling of bodies. The liquid being heated, it would be necessary to produce evaporation by the air; for this, the liquid must flow from top to bottom in apparatus which the outside air is obliged to move in the opposite direction. A vertical cylinder containing balls, on which the liquid divides itself, and between which the air would circulate from the bottom upwards, would be better. We could also use the apparatus employed for *cooling liquids by evaporation*, which we will see *later on*. If the rest of the heat from the condensed water was used for heating the air, it is evident that all the heat proceeding from the cooling could be utilised for evaporating; supposing the water to be at 40° and cooled to 10° the cooling of 1 kilo could evaporate 0·05 kilos of the liquid.

EVAPORATION BY HOT OIL, OR SOLUTION OF SALTS.

1635. To carry the heat of the furnaces into the liquid to be evaporated, various substances have been used, principally with the object of bringing in contact only those bodies the temperature of which are slightly

above that at which evaporation should take place. We have seen that steam perfectly fulfils this object.

"Wilson," to heat liquids to a temperature of 100°, made use of oil, which he partially heated and caused to be circulated by a pump, through a serpentine immersed in the vessel containing the liquid. This arrangement has been used for concentrating syrups, the oil was raised to about 120°, at this temperature no sensible quantity of vapour is thrown off. Purified whale oil has been found better than any other. "Wilson's" apparatus has several serious drawbacks; 1st, it is difficult to regulate the fire so as to keep the oil at the necessary temperature; 2nd, a considerable quantity of the oil is evaporated or decomposed; 3rd, using a pump brings in complications.

We could also use saline solutions which only boil at high temperatures, such as solutions of carbonate of potass or chloride of lime, but it would be necessary to keep these solutions constantly at the same degree of concentration by exhausting the condensed vapours. The use of steam at a pressure of 3 to 5 atmospheres is preferable in an economical sense, and this low pressure is open to no danger which cannot easily be provided against.

CHAPTER VII.

EVAPORATION IN VACUUM.

1636. Evaporation in vacuo can be carried on at the ordinary temperature, by means of matter having a great affinity to water, and placed in the same vessel as the liquid to be evaporated. The cost of this mode of evaporation depends on: 1st, the expenditure of mechanical power to produce the vacuum; 2nd, the value of the fuel necessary to dry the absorbing matter. This method of evaporation can only be applied on a small scale. We will, however, return to it in the next book, as it can be used with advantage for the dessication of animal matters.

1637. The simultaneous use of vacuum, or at least a reduction of pressure and of heat is now much in vogue, especially in refineries and sugar factories, as they can evaporate without air contact, and do it very rapidly, both of which circumstances are favourable to the preservation of the syrups. This method of evaporation was first put

into practice in England by Howard, but it has had several modifications applied to it, chiefly in the means for forming the vacuum. We will first describe Howard's apparatus, and afterwards those which have been brought out as substitutes for it.

HOWARD'S APPARATUS.

1638. This apparatus is represented in section in figure 33. A is a boiler for boiling the syrup; it is formed of two copper pans, strongly bolted together, and has a double bottom, into which the vapour is supplied by the pipe C; D, the condensed water pipe on which is fixed the air cock; E, the dome in which the vapours are collected; the syrup, which may be mechanically drawn in with the vapour, falls again into the vessel; G, the condensing vessel, to which a pipe is attached, and communicates with the air pump; this pump maintains the vacuum, but is not shown in the plan; the cold water enters the space C by the opening H, by moving the handle I, the valve K and the piston L are raised; F, the vapour pipe from the pan to the condenser. Pipe F' is for returning the liquid drawn in by the vapours into the space O, from where it is easily drawn by the cock R. M is the cold water feed pipe, N a proof-stick for taking a proof of the syrup in the vessel without opening communication between the interior and the air outside. Q is a thermometer which indicates the temperature of the syrup.

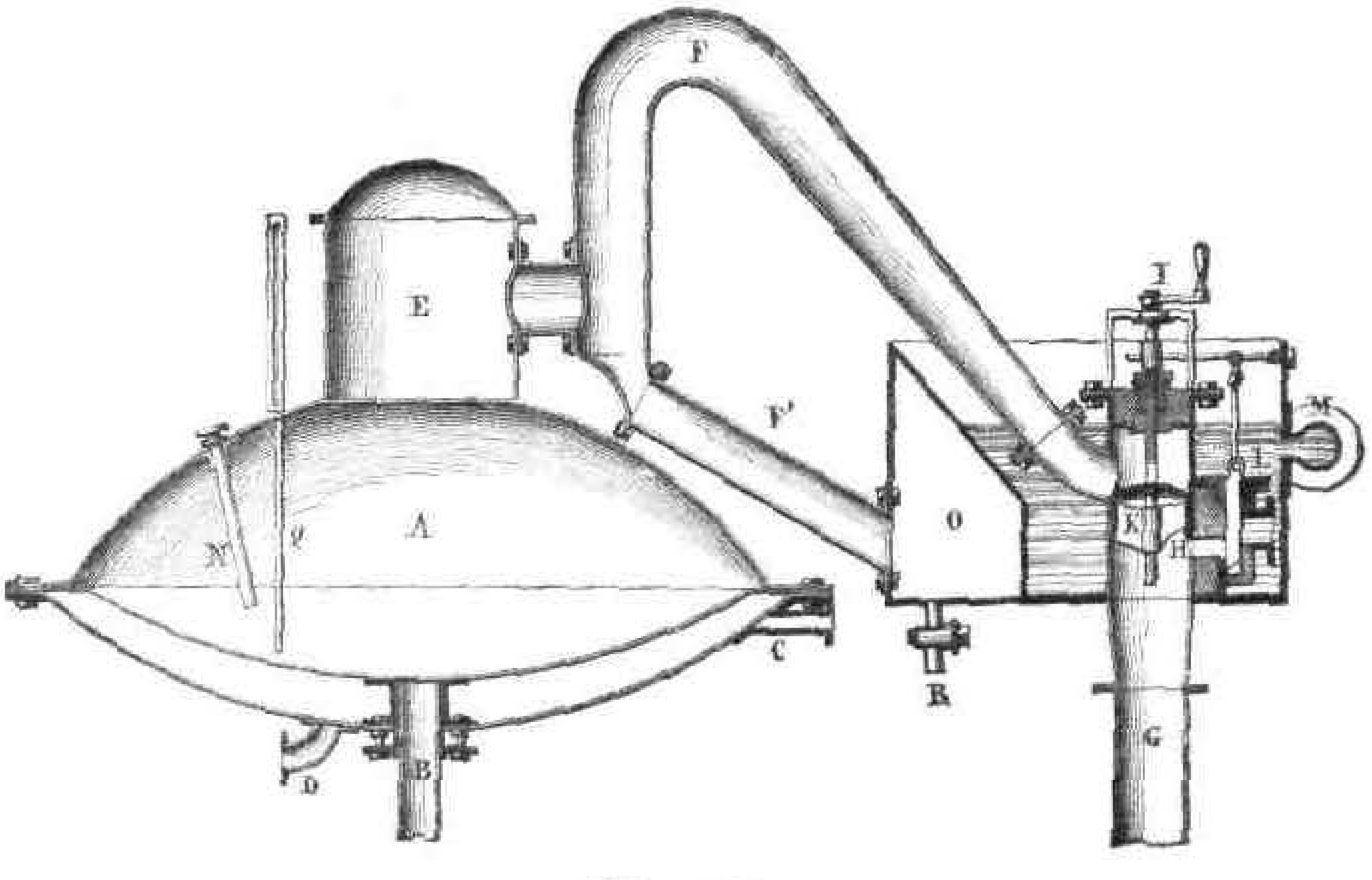


Fig. 33.

In these apparatus, there is always a difference of 9 to 12° between the temperature of the condensed water and that of the syrup, and the interior pressure is always between 0·50 metres and 0·55 metres mercury, or $\frac{50}{76}$ and $\frac{55}{76}$ of atmosphere. The air pump requires to be two horse power, for working 12,000 kilos gross of sugar per day, or to manufacture 100 loaves per hour, or 600 to 700 kilos of white sugar, and for condensing 500 kilos of vapour per hour. The volume of injection water used is 10 to 11 cubic metres per hour, the condensed water being at 30°. The Howard apparatus has been widely used, and has received several important improvements, such as a serpentine has been placed inside to increase the work, and the circuit which the steam traverses before arriving in the pipe where the injection water is introduced, has been lengthened in various ways, in order to collect more completely the liquid which may have been drawn in; glasses for seeing into the inside of the vessel have also been added.

We will now give a short account of the apparatus which have been tried as substitutes for Howard's.

ROTH'S APPARATUS.

1639. This only differs from Howard's in one particular, that the vacuum is produced by steam; figure 34 represents a section of it. The boiling vessel A, is similar to Howard's, but it contains a serpentine in which the steam circulates. D is a vessel made of iron for condensing the vapour, it is fitted with a vacuum gauge *m*, a water gauge *n*; E is the steam pipe communicating with the boiler; F, G, H, cocks for admitting the steam to the double bottom, the serpentine, and the vessel; F^1 and G^1 cocks for the condensed water from the double bottom and the serpentine; *i*, butter cock to prevent the mass becoming frothy; K, syrup supply cock and pipe; L, outlet cock for the boiled syrup which is discharged into the vessel O; M, the vapour pipe to the condenser; N, metallic perforated plates, through which the cold water runs in very small streamlets, and through which the vapour passes; P, injection cock connected to the pipe S, which supplies the cold water; Q, cold water supply cistern; R, cock for discharging the hot water and the air at the end of each stroke. It is worked as follows: The vessel being empty the cocks H and R are opened, all the

others being shut, the steam rushes into the vessel and into the condenser, a mixture of air and steam escapes by the cock R, and after a few moments, when it is supposed that all the air has been driven out, these cocks are shut, and the cock K is opened to admit the syrup, at first the

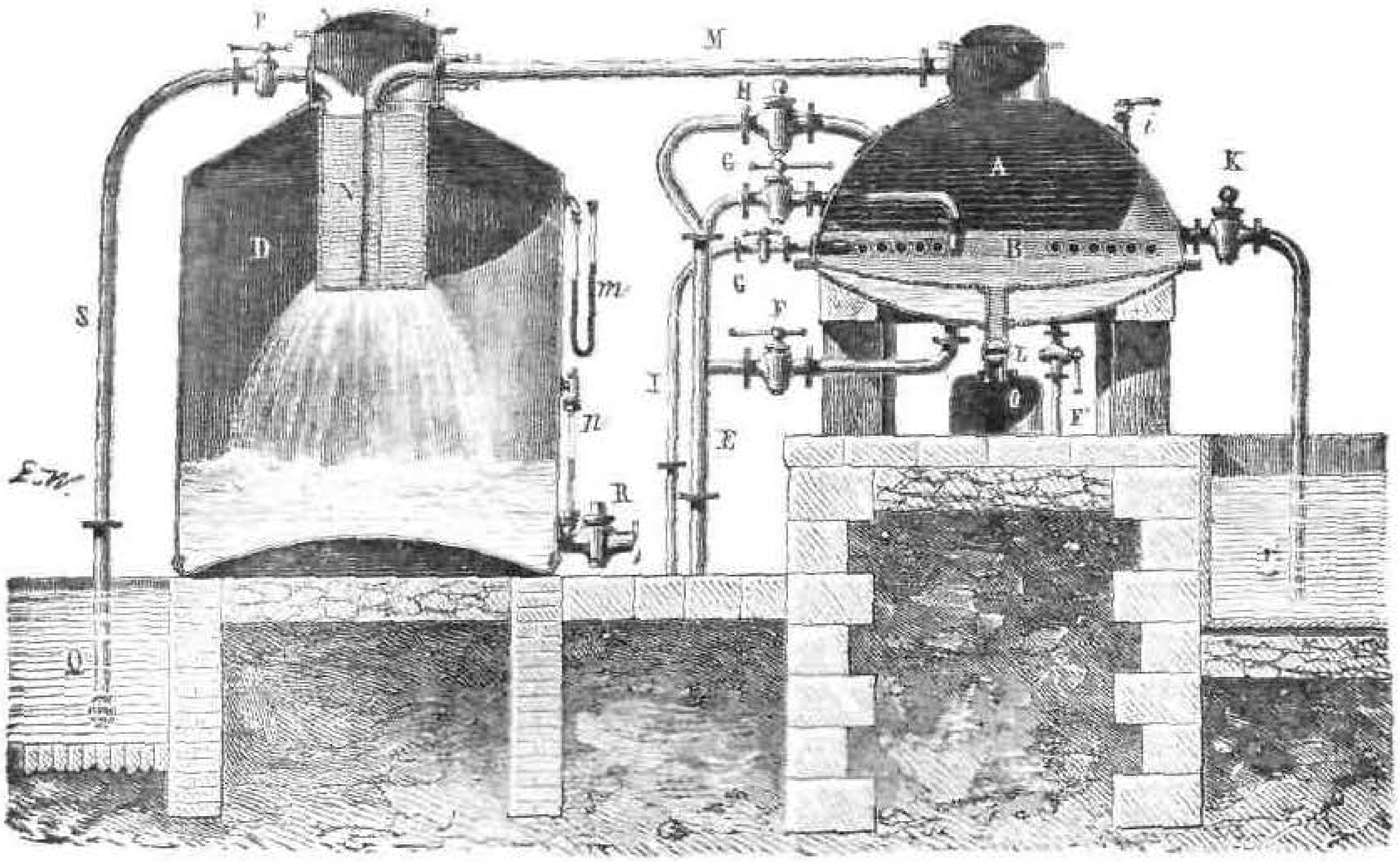


Fig. 34.

liquid rises slowly with the progressive condensation of the vapour in the vessel, caused by the cooling of the outer case, afterwards very rapidly when a portion of the syrup has been supplied into the vessel, on account of the rapid condensation which its entrance causes. When the syrup in the cistern is drawn out to a certain level, the cock K is shut, and F and G opened to admit the steam into the double bottom and the serpentine. The condensed water cocks are also opened, and in a few moments afterwards the injection cock P. In a short time a proof is taken of the syrup, and when it has arrived at the required point the injection cock is closed; the syrup is hot, and when it reaches 80 or 90° the cock L is opened, also the air cock, and the boiled syrup runs out. In order to begin a new operation the cock R has to be opened to allow the hot water to run out, and steam is again admitted to the vessel, to drive out the air which fills both it and the condenser.

The consumption of water in Howard's and in Roth's apparatus should be alike, the boiling taking place at the same temperature. Mr Roth estimates it at four times the weight of the syrup boiled. According to Mr Roth, a vessel two metres in diameter should be sufficient for a factory treating daily 25,000 kilos of raw sugar.

At the time of the appearance of these apparatus the inventor claimed that they consumed less steam to form the vacuum, and to maintain it, than that of Howard's, but experience has proved that this is not so. They require more steam, and consequently more fuel to do the same work as those in which the vacuum is produced and maintained by mechanical action; therefore, these latter are preferred, and are the only ones used.

MESSRS. TRAPPE AND LOUVIER-GASPARD'S APPARATUS.

1640. These constructors invented and tried an apparatus similar to Roth's, in which the condenser was much less, and terminated in a vertical pipe about 10 metres high, the lower end of which was immersed in a vessel constantly full of water, which received the condensed water. This apparatus consumes less steam than Roth's, but it requires a deep well, or else the apparatus must be placed in the upper storey of the building; it has not been adopted by the trade. Mr Walkhoff, however, in his book gives a design of a condenser used in Germany, and founded on this principle; the advantages which Mr Walkhoff finds in a diminution of work for the water pump are more than counterbalanced by the cumbersomeness of the apparatus.

1641. It is important to note that it would be possible to reduce to almost nil the real expenditure of the air pump in Howard's apparatus, by using high pressure steam, and a non-condensing expansion engine, and by making the exhaust steam pass into the double bottom, or into the serpentine of the pan. The work required of the pumps is really insignificant.

MR. PELLETAN'S APPARATUS.

1642. Mr. Pelletan invented an apparatus similar to Mr Roth's, but in which the discharge of the air was produced by injecting vapour from outside to inside. To

understand this method, we must imagine a space A B (fig. 35) of any form, fitted with pipes, one of them, E, communicating with the outside, another, F, with an enclosed space in which a partial vacuum is formed, and lastly C communicating with a steam boiler through a conical pipe D, the end of which is only at a short distance from the opening of pipe E, the diameter at the end being less than that of this pipe. The jet of steam carries with it the air from space A B, and consequently that from the space with which A B communicates through F, it produces there a partial vacuum. By using steam at 3 atmospheres, and with diameters in proportion to those stated by Mr Pelletan, the pressure in the space A B, and in the other space communicating with it, is lowered to 0·50 metres of mercury, or $\frac{50}{76}$ atmosphere. Mr. Pelletan's apparatus is very ingenious, several manufacturers were taken in by its simplicity, but it was soon discovered that it consumed a great quantity of steam, and that it was difficult to utilise the mixture of steam and air after its action ; it has been completely abandoned. This method of making a vacuum may be used at any time under some circumstances in preference to Roth's, for small apparatus where it is not worth the cost of a pump. The principle of Mr Pelletan's apparatus is the same as the principle of the injector, and it has been taken up, as we have mentioned, by Mr Körting, of Hanover, and utilised for forming the vacuum in the condensers of steam engines.

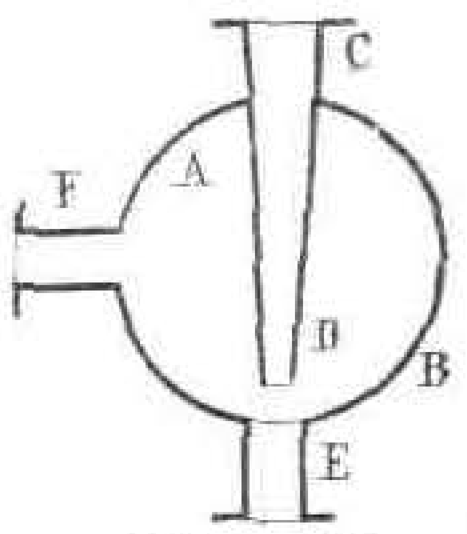


Fig. 35.

MR. DEGRAND'S APPARATUS.

1640. The drawback to the preceding apparatus is that they consume too much water, and this water carries off heat which is thereby lost. Mr. Degrand wished to remedy this, by commencing to evaporate the syrup before placing it in the evaporating vessel. In his apparatus the vacuum is first formed by the steam (fig. 36.) ; it consists of three distinct parts, an evaporating vessel arranged like all apparatus for boiling *in vacuo* ; an enclosed tank placed below the boiler, for the purpose of receiving the boiling syrup, and lastly, the apparatus for condensing the vapours by the syrup.

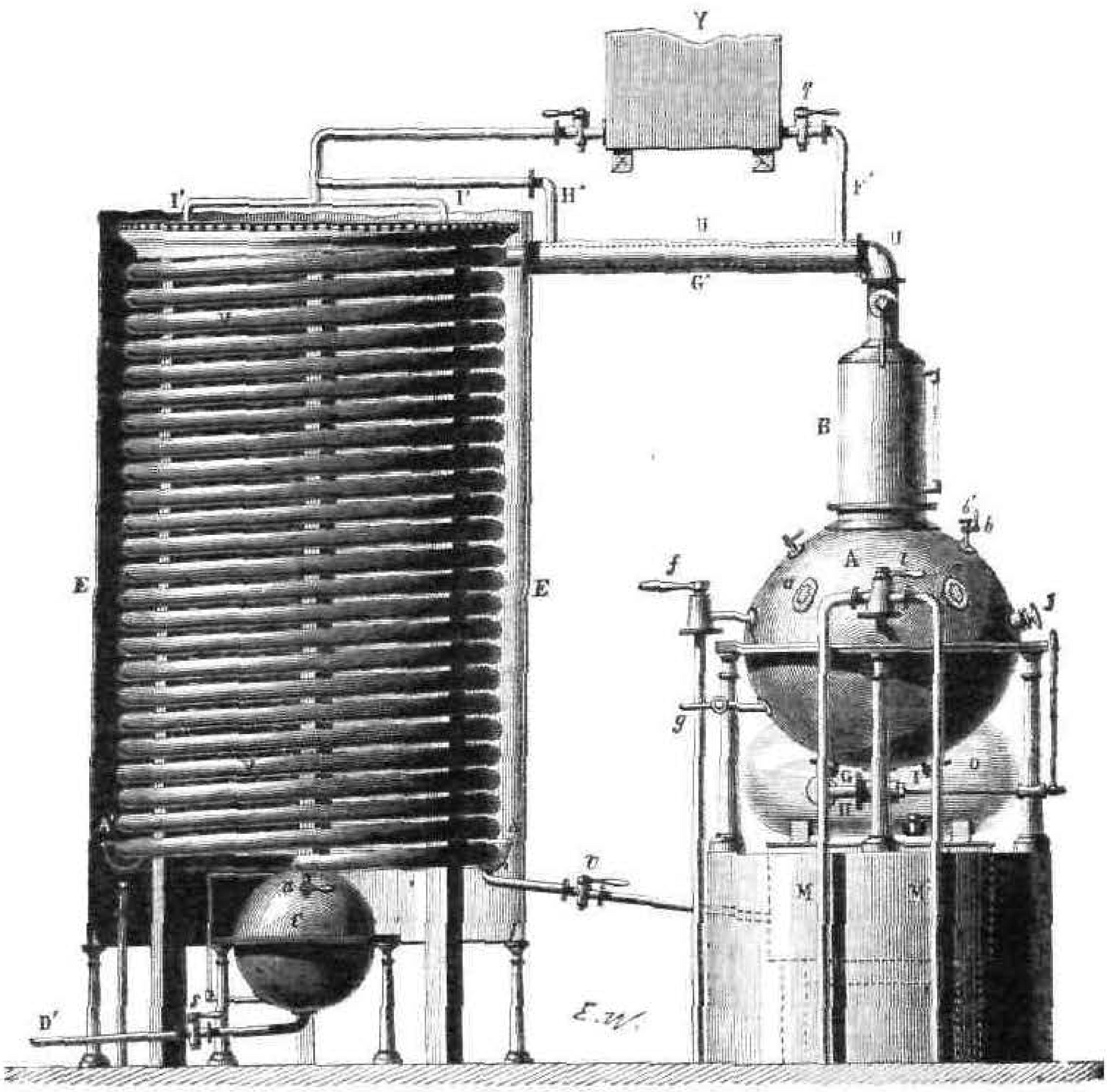


Fig. 36.

A is a copper boiler formed of two spheroidal bowls, accurately attached and sufficiently solid to resist atmospheric pressure. It is surmounted by a dome B, which collects the vapours escaping from the syrup in A. The syrup is heated as in the other apparatus of the same kind, by steam which circulates in the double bottom of the vessel and serpentine, the cocks *f* and *g* regulate the supply of steam, G and *e* the condensed water pipes, the cock H is to empty the vessel as soon as the operation is concluded. To discharge the air out of the apparatus it is necessary to open the steaming out cock *f*, supplying at the same time steam into the serpentine, then open the cock *u*. As soon as the air is discharged the cocks *u* and *f* are shut and *q* is opened, then the liquid contained in the upper tank Y, commences to flow into the condenser V, and the vacuum

is formed. When this operation is finished, the cock *i* is opened, and the charge of syrup to be boiled is drawn into the vessel through the pipes $M\,M^1$; pipes *f* and *g* are opened to supply steam into the double bottom and serpentine, boiling takes place almost immediately. The vapours produced in the vessel rise into B, and pass into the pipe U, which leads them to the condenser V. This latter consists of a serpentine enclosed in an iron cylinder E E, open at top and bottom, the vapour circulates in the serpentine, and is condensed by the syrup or juice from the reservoir Y, which falls on to its surface; by opening the cock q^1, the syrup descends through the pipe F^1 into the cylinder G^1, which is closed at both ends, and surrounding the pipe U, after being heated it passes through the pipe H^1 and $I\,I^1$, into an annular vessel perforated with a number of holes which distribute it over the serpentine. The portion of syrup which is not evapora'ed is received in the annular vessel $A^1\,A^1$, and is led from there into a lower reservoir, through a pipe fitted with a cock *r*.

When these apparatus are placed in refineries the juice is simply replaced by water.

The outside cylinder gives a great velocity to the air, which greatly accelerates evaporation. The water from the condensation of the steam in the serpentine flows into the vessel C, and is discharged through the pipe D^1, which is fitted with a cock *s*; it can be emptied whenever necessary, without permitting the air to return into the apparatus, and without suspending the evaporation; in order to do this the cock *u* must be closed, and the vessel C put in communication with the steam boiler, and the discharge cock *s* opened; as soon as the water is discharged the cock *s* is closed and *u* opened; the cylinder O, which is below the vessel A, receives the boiled syrup from A by opening the cock H, a vacuum being first formed in it by vapour. In refineries where water is used for condensing the vapour, that coming from the serpentine would be sufficient in case of need.

It will be seen from the above that: 1st, if there were no leakages by the cocks, &c., the vacuum once formed in the apparatus could be maintained indefinitely, and at each operation it would suffice to form a vacuum in the cylinder O, and in the reservoir C, which would consume a volume of vapour equal to only three or four times the volume of syrup before being boiled; 2nd, in refineries, no

water would be required for the condensation; 3rd, in home sugar factories the condensation of the vapour could be used to evaporate the syrup, which would double the useful effect of the fuel.

But these results are not completely attained in practice, and an air pump has been found necessary to maintain the vacuum, as we will see in the following description of Messrs. Derosne and Cail's apparatus, which is chiefly used in sugar factories.

MR. DEGRAND'S APPARATUS, MODIFIED BY MESSRS. DEROSNE AND CAIL.

1644. This apparatus is a combination of Howard's and Degrand's; the vacuum is formed and maintained in the vessel by an air pump, and the steam is condensed by the transmission of heat through a serpentine, to a liquid which is evaporated by a current of air. Figures 37 and 38 represent a vertical section and plan of that part of the apparatus next to the pan. This is arranged like all others for evaporating in vacuo; only the dome which surmounts it is closed by a valve, worked by means of a lever, attached to a rod, which passes through a stuffing box, for establishing or intercepting communication with the rest of the apparatus; C, the vapour supply pipe from the pan; D, cylinder which receives the vapour and is the whole height of the apparatus, and acts as a save-all for any liquid that may be drawn in, the height of this liquid is indicated by a gauge *u*, and can be drawn off through the cock *r* when there is no vacuum in the apparatus; E E, pipes for supplying the vapour into the two serpentines F F, which are each formed of a single tube, on a vertical plane, and fixed in a wooden case; G G, pipes for connecting the serpentines with the pump; H H, reservoirs for the cold liquid placed above the serpentines, from which the liquid is discharged through a large number of small holes distributed over their entire length; the perforated plates are toothed the full length of their lower surface so as to spread the liquid uniformly; the supply cocks for the reservoirs H, are worked by means of a handle and rod I, I; K, K are reservoirs for the liquid after passing over the serpentines. In the home sugar factories the volume of syrup which flows on the serpentines is reduced to about half; it is led to the tank L,

from whence it is taken to the evaporator by pipe M, and concentrated to 26 or 28° Baumé, a density which is necessary for the second filtration; syrup which has only been once filtered may also go to the evaporator.

Figs. 37, 38, and 39.

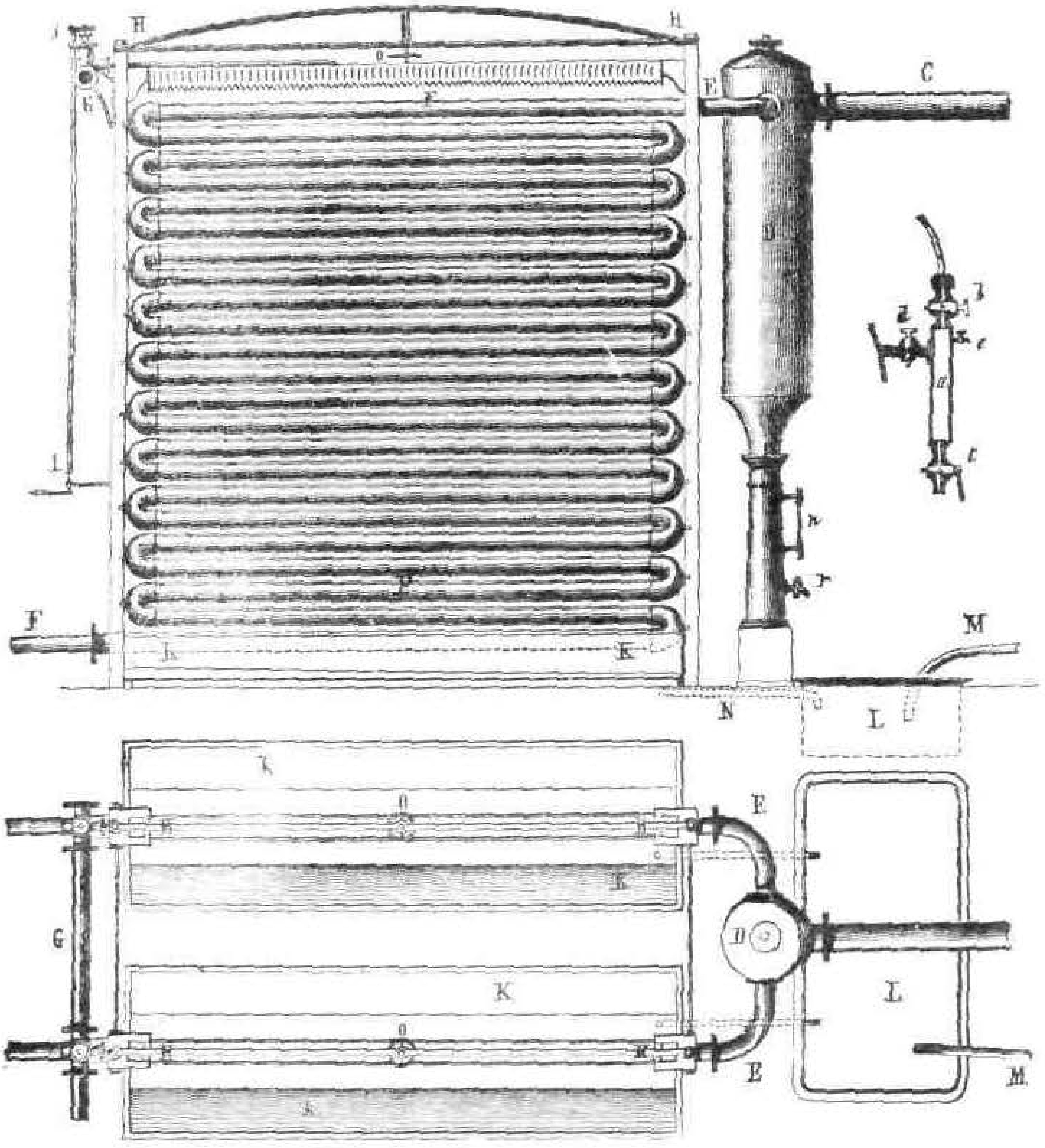


Figure 39 is a section of a small apparatus for taking proofs of the syrup from the vessel, without opening communication with the outside; *a* is a cylinder which communicates with the upper and lower part of the vessel by the pipes *b* and *d*, and with the outside by the cocks *c* and *e*; by opening the first two, the cylinder *a* fills with liquid; and by opening the two others the liquid can be received in a gauge to test its density.

1645. The ingenious method of condensation invented by Mr Degrand, after being frequently used, chiefly in the Colonies, is now almost entirely abandoned, in spite of the great economy in the consumption of steam. It appears that the effect varies with the temperature of the outside air, and the thickness of the deposit formed on the tubes; further, the syrup, by its contact with the air, is subject to a certain deterioration. Also many manufacturers, having water at their disposal, prefer to expend more steam in heating, and to use Single Effet apparatus, condensing by cold water injection like Howard's. The condenser may be made in many forms; the following has been adopted by Messrs. Cail and Co. :—(fig. 40) A B is a cast-iron cylinder, divided into two parts by a partition C D, provided with a pipe F F, open at both ends; the vapour enters by the pipe G, the liquid drawn in collects round the pipe F F, a gauge indicating the height of it; the vapours descend through F F, with the top cold water injection; there is also a bottom injection below C D; the uncondensed vapours and air are drawn by the air pump through pipe H.

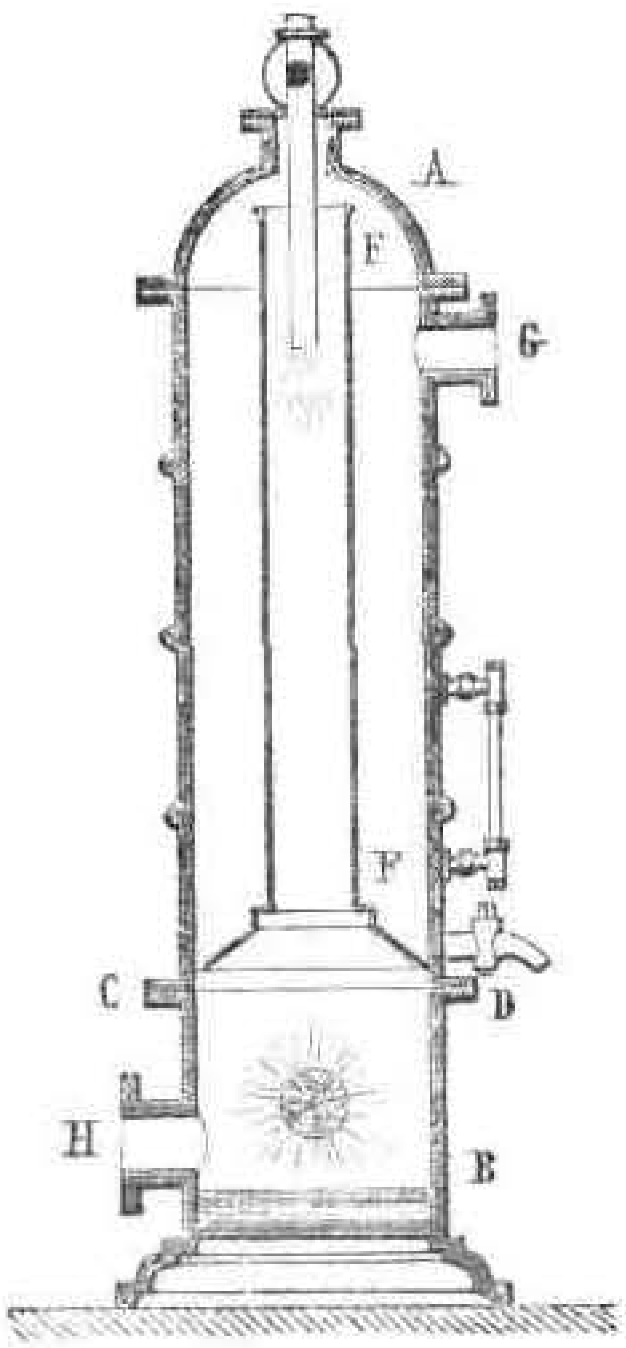


Fig. 40.

1646. The vessels for boiling to grain in vacuo now used are a little different to those we have just been describing; they consist of a cylindrical boiler, terminating top and bottom with a spherical bowl, and communicating with a save-all, similar to figure 40, which we will describe in the following chapter on the Triple Effet; this save-all is for the purpose of collecting the scum and portions of syrup carried away by the boiling, and to return them into the vessel or pan; at the bottom is the cold water injection and communication with the air pump. We will limit ourselves here to describing the vacuum pan, which is represented in elevation and section in figures 41 and 42. It contains three independent serpentines, as shown in the section, the serpentines are heated internally with steam at 5 atmospheres; for a daily work of 1,500 hectolitres of juice, the dimensions of the pan will be 2·30 metres

diameter, the centre belt 1·60 metres high, the lower bowl 0·60 metres, and the top 0·96 metres; the serpentines are made of copper, having an interior diameter of 125 millimetres. The first serpentine is formed of four and a-half spirals, having a heating surface of 7·46 square metres; the second serpentine is formed of three spirals, having a heating surface of 4·74 square metres; the third has also three spirals, and a heating surface of 6·10 square metres. The total heating surface being 18·24 square metres.

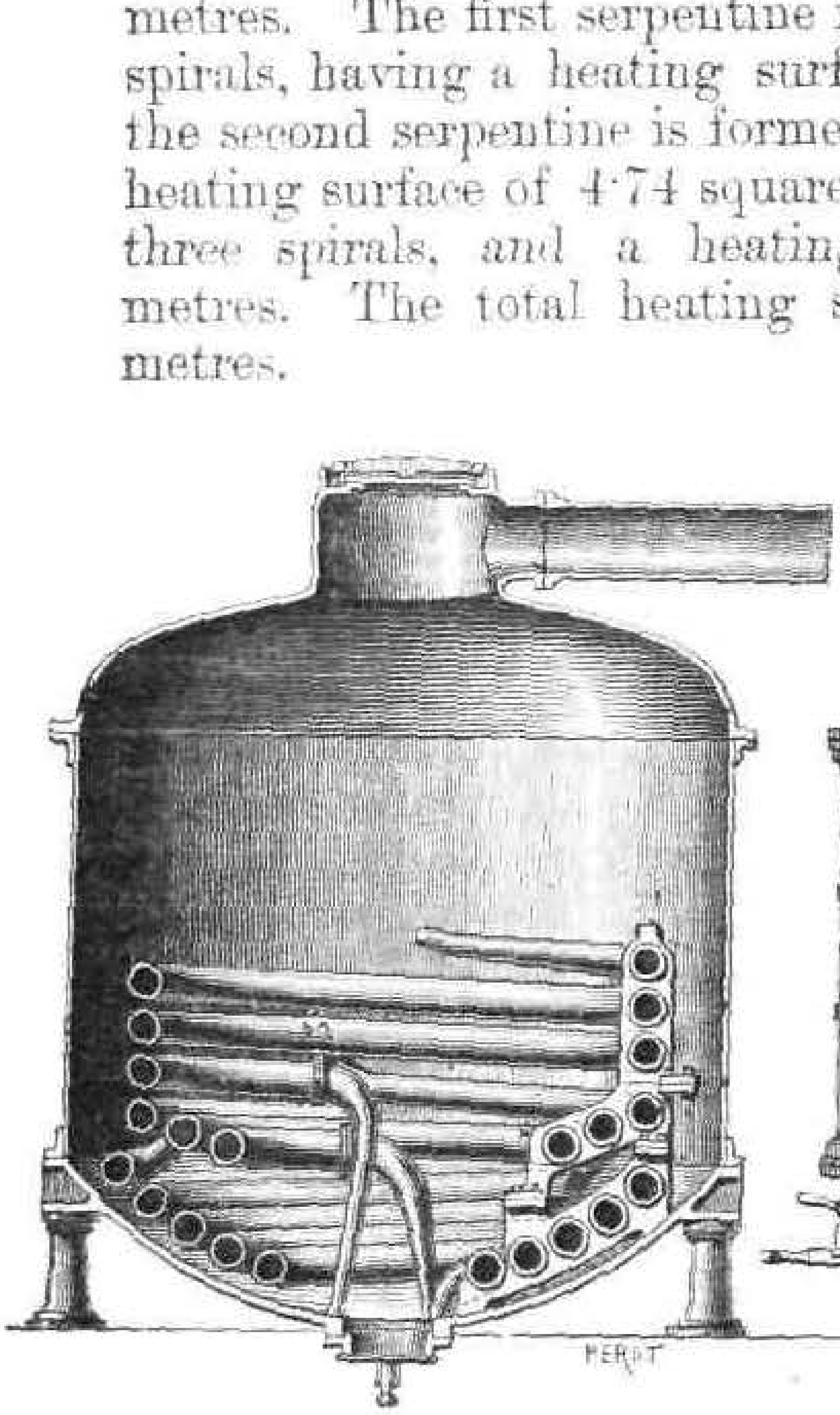


Fig. 41.

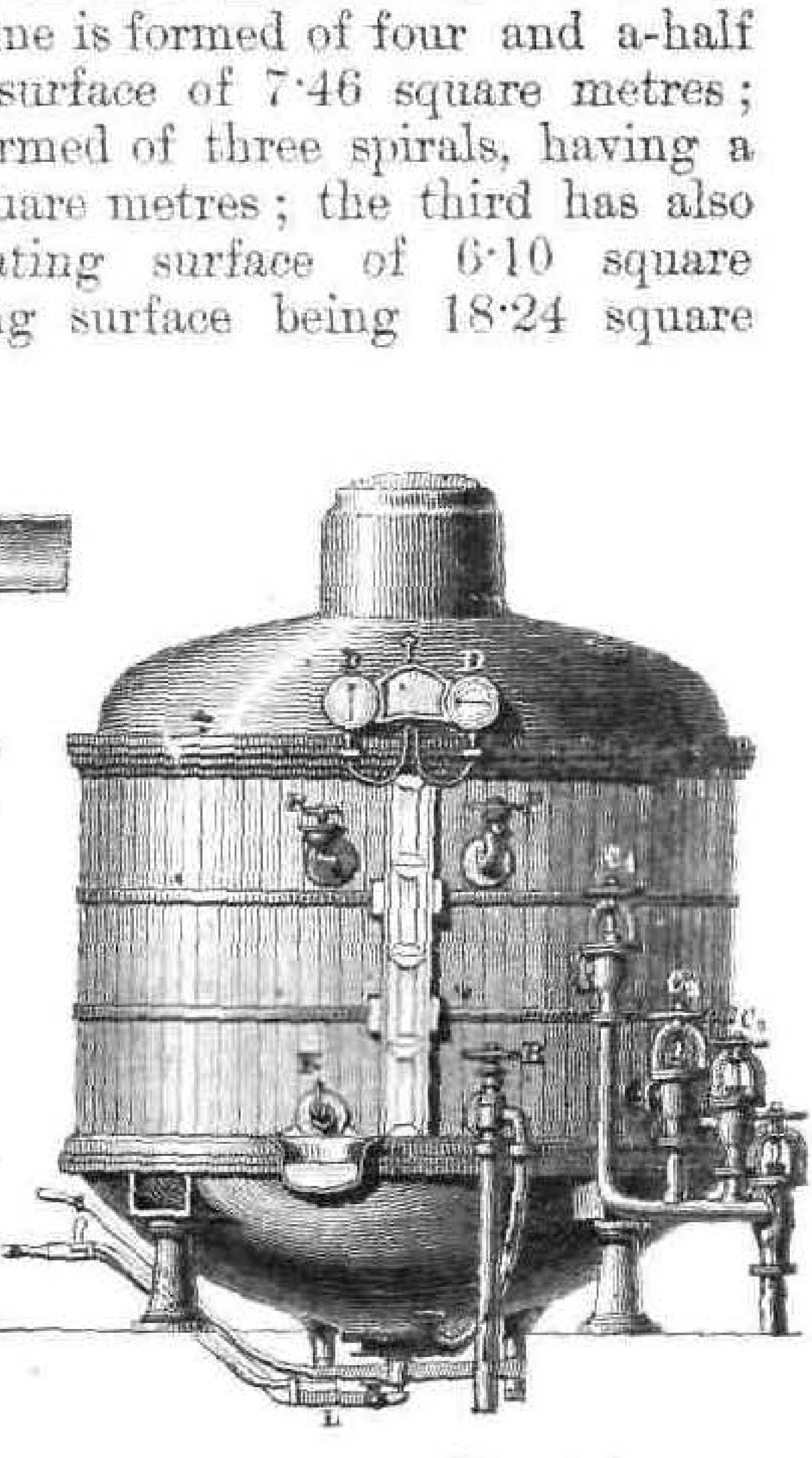


Fig. 42.

The juice already concentrated to 20° Baumé is supplied into the pan by the pipe A, fitted with a valve B, the steam is supplied to the serpentines by three pipes, fitted with valves C, C[1], C[2]. Thick sight glasses are fixed from top to bottom in such a way that all that goes on inside may be seen from the outside; and to facilitate this, a glass is fitted at the far side of the pan, and lighted up by a jet of gas; two gauges, D, D, are fixed to the upper part of the pan, one to indicate the vacuum and the other the pressure in the serpentines; F is a cock for admitting air when it is necessary to empty the vessel; H is a cock to admit a little grease or butter when scum is produced in too large a quantity; K is the proof-stick, provided with a small cavity, which fills with masse cuite, and can be withdrawn.

L is the discharge or outlet valve; it is formed of a simple plate, sliding laterally on its seat, and is perfectly planed; it is tightened by means of a second lever. The use of this method of closing by lateral sliding is determined by the presence in the boiling mass of sugar crystals, which do not allow valves working by direct application to shut tight.

The pan is lagged with wood, to protect it from the cold outside.

The capacity of the pan which has been described is 60 hectolitres, that is to say that after each operation, 60 hectolitres of masse cuite may be withdrawn, consisting of

Sugar - - - - - -	76·85	
Cinders or salts - -	6·07	100·00
Water - - - - - -	17·08	

The masse cuite is at about 46° Baumé, and weighs 150 kilos per hectolitre; the weight of the 60 hectolitres is therefore $60 \times 150 = 9000$ kilos, containing $\frac{9000 \times 76{\cdot}85}{100} =$ 6916·50 kilos of sugar and $\frac{9000 \times 17{\cdot}08}{100} = 1537{\cdot}20$ kilos of water.

The syrup at 20° Baumé on leaving the Triple Effet contains:—

Sugar - - - - - -	30·00	
Cinders - - - - - -	2·16	100·00
Water - - - - - -	67·84	

Therefore, the quantity of water which the syrup at 20° contained when supplied to the vacuum pan is equal to

$$\frac{6916{\cdot}50 \times 67{\cdot}84}{30{\cdot}00} = 15640{\cdot}5 \text{ kilos.}$$

The duration of the strike is, on an average, 12 hours; the quantity of water evaporated in 12 hours is 15640·5 kilos—1537·2 = 14103·3 kilos. Boiling takes place in the pan at 70°, the temperature of the steam in the serpentines is 152°, the difference is therefore 82°, the heating surface being 18·24 square metres × 82° = 1495·68 square metres, with an excess of temperature of 1°; the quantity of water evaporated per hour is $\frac{14103{\cdot}3}{12} = 1175{\cdot}3$ kilos; consequently the quantity of water evaporated in

the apparatus per square metre per hour, and for one degree of difference of temperature is

$$\frac{1175 \cdot 3}{1495 \cdot 68} = 0 \cdot 78 \text{ kilos.}$$

In order to calculate the quantity of steam which condenses in the serpentine, let us note that it was necessary to heat the 9000 kilos of masse cuite from 60°, requiring $9000 \times 60 = 540,000$ calories, plus the evaporation of the 14,103·3 kilos to 70°, which will give the quantity of heat required as $14,103 \cdot 3 \ (606 \cdot 5 + 0 \cdot 305 \times 70 - 10) =$ 8,713,723 calories, or a total of 9,253,723 calories; if we admit that the water condensed leaves the pan at a temperature between that of the steam and that of the juice, say about 110°, the quantity of heat ceded by each kilo of steam condensed will be $606 \cdot 5 + 0 \cdot 305 \times 152 - 110 = 542 \cdot 86$, the total quantity of vapour condensed will be $\frac{9253723}{542 \cdot 86}$ as the heat is required for 12 hours with an excess of temperature of 82°, and on a heating surface of 18·24 square metres the quantity of vapour condensed per hour per square metre and per degree of excess of temperature will be

$$\frac{9,253,723}{542 \cdot 86 \times 12 \times 82 \times 18 \cdot 24} = \frac{9,253,723}{9,743,340} = 0 \cdot 95 \text{ kilos.}$$

If we take into account the losses of heat by the external surface of the pan, it is probable that the condensation will be equal to at least 1 kilo per square metre per hour and per degree of excess of temperature.

CHAPTER VIII.

EVAPORATING APPARATUS IN WHICH THE HEAT IS USED SEVERAL TIMES.

1647. After what has been said on the subject of distillation, it may easily be understood that the same heat can be used several times, and that distilling by Multiple Effet may be applied to the concentration of solutions. Mr. Degrand's apparatus, which we have already described (paragraph No. 1643), proves to be one of the first examples of the double application of heat. In each particular case there are conditions to fulfil which are sometimes incompatible with a repeated use of the steam, or at least which limit the number of effects which can be produced.

First, if the evaporation should take place in the air at the ordinary temperature, or at a temperature lower than that of the boiling point of the liquid, then the evaporation is caused by renewing the air, and, in this case, it would be extremely difficult to use the heat contained in the vapour several times, on account of the difficulty encountered in condensing the steam mixed with air. But if the liquid is evaporated in a closed vessel at a temperature above boiling point in the air, or if the boiling takes place in vacuo, the heat expended for the first operation can be utilised several times, but only in complicated apparatus, which require much care in their construction and handling, at the same time producing a considerable economy of fuel.

1648. Figure 43 represents a vertical section of an apparatus, constructed many years ago by Mr Derosne, for concentrating beetroot juice, in which 1 kilo of coal evaporated 9 to 10 kilos of water. A B and C are three pans placed at different heights, and heated by the same furnace F; the liquid to be evaporated is contained in the tank D, from which it runs into the vessel E, and successively into the three pans A, B, C, making a long circuit on the bottom of each; after having run through the three vessels, it is collected in the vessel M. These pans are fitted with covers with water closures, and pipes which conduct the vapours into the double bottom of the

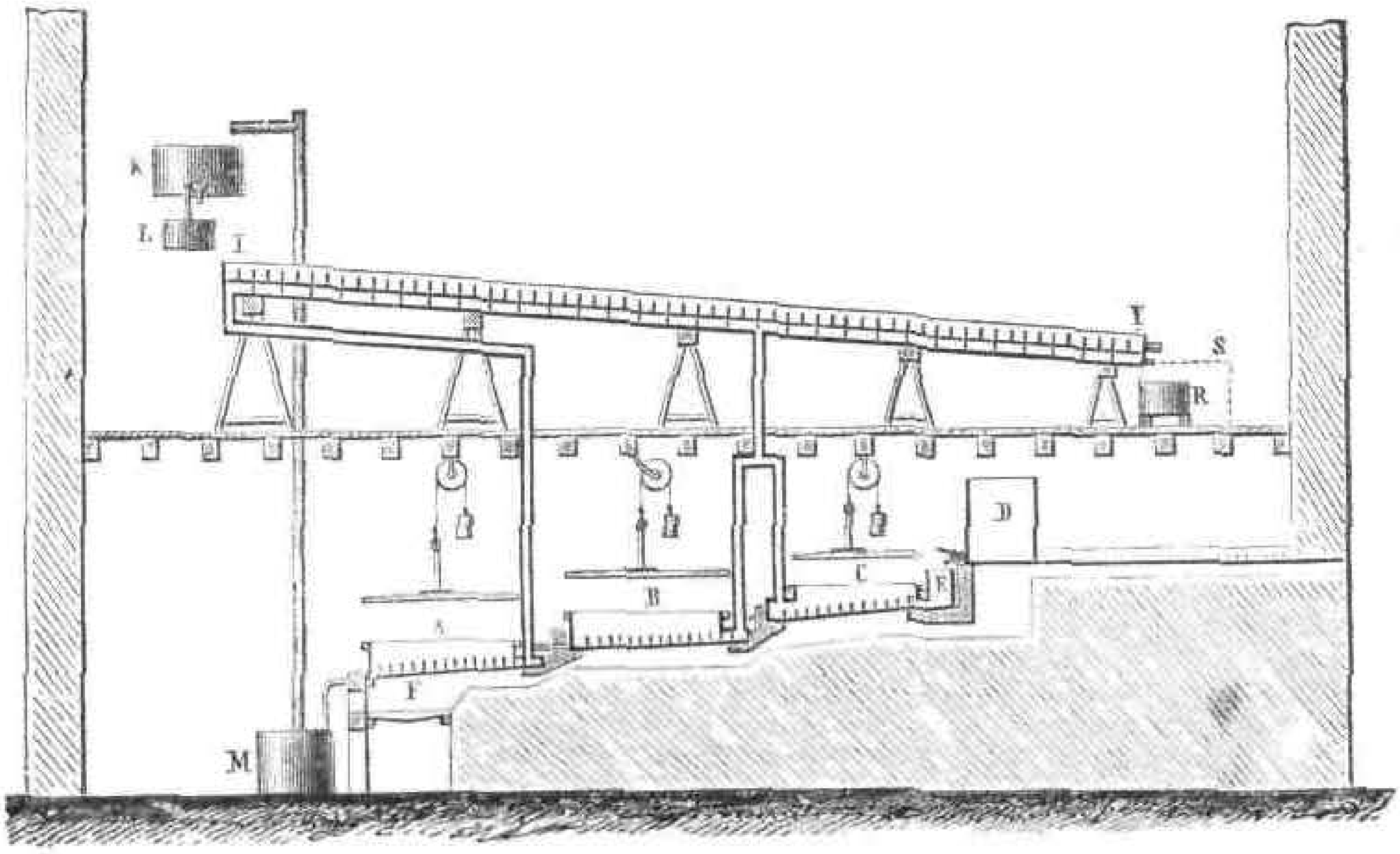


Fig. 43.

large inclined metal case I, I. The vapour, in traversing the double bottom, condenses, and the condensed waters are collected in the vessel R. The liquor to be concentrated in tank K flows continuously into the vessel L, and from it into the upper part of the chest I, which, after having passed the numerous sinuous turnings of the chest, is received in the vessel S. This supplies the tank D; the tank M supplies the tank K. This apparatus has been completely abandoned.

1649. Figure 44 represents an arrangement applied some years ago, for the concentration of solutions of carbonate of soda. The apparatus consists of three tanks or boilers A, B, and C, placed one after the other at different heights. The first is either placed upon the naked fire, or on a brick arch over the fire. The second is provided with a cover, having a water closure, and the vapours which are produced are condensed in a serpentine in the third vessel. Each is fed by the following one by means of the cocks D and E. For a consumption of 20 kilos of coal per hour, the heating surfaces should be 10 square metres, the grate surface 0·21 square metres, the section of the flues 0·07 square metres. By this arrangement the useful effect is increased by at least one third. Under certain circumstances the vapour produced in the first vessel could be utilised during a certain part of the concentration.

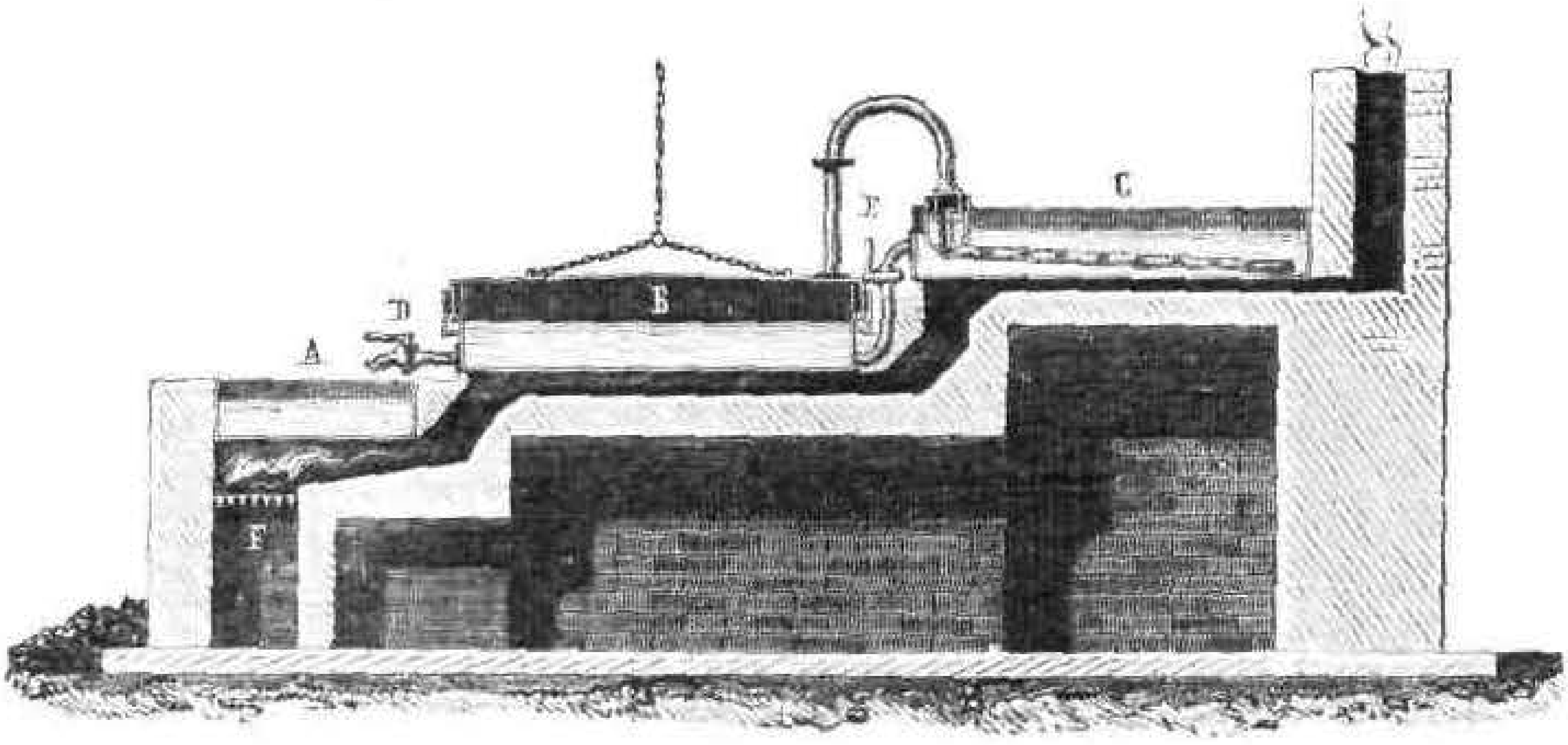


Fig. 44.

1650. When the liquid can be evaporated in closed vessels, an arrangement similar to that which we referred to when speaking of distillation, may be made use of, as represented in figure 45. We will first suppose that the evaporation is to take place in vacuum, A A′ A″ are the

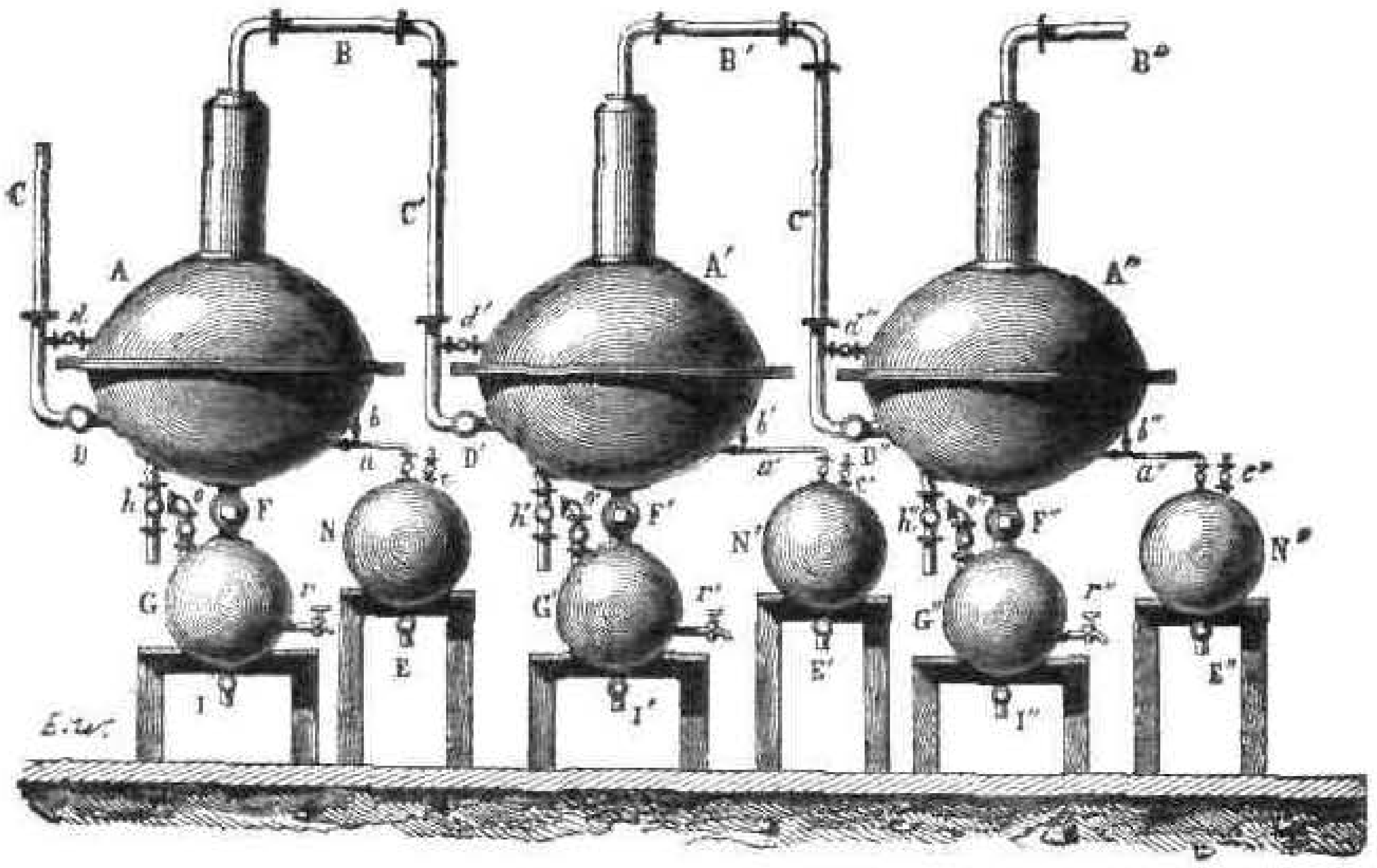


Fig. 45.

three vessels for boiling in vacuum, fitted with a double bottom, a serpentine, and all the accessories usually requisite for this kind of apparatus. The vapour produced in the first, escapes by the pipes B and C′, and is distributed by the cocks *d′* and D′ into the serpentine and double bottom of the second vessel; the vapour from the second passes into the serpentine and double bottom of the third through the pipes B′ and C″, and the cocks *d″* D″; finally the vapour from the last passes off through the pipe B″ and condenses in a serpentine exposed to the air as in Degrand's apparatus. F F′ F″ are cocks for emptying the vessels of the juice after it is concentrated, G G′ G″ are the reservoirs for receiving it, the vacuum being formed in them by means of the cocks *o o′ o″*; I I′ I″ cocks for emptying the reservoirs; *a a′ a″* and *b b′ b″* are the condensed water cocks for the double bottoms and serpentines; N N′ N″ reservoirs for the condensed water; *h h′ h″* feed pipes for the vessels; *r r′ r″* air cocks.

A vacuum being formed in the apparatus, and the vessels charged with syrup, the steam from the boiler is supplied to the serpentine and double bottom of the first vessel, the cocks D D′ D″ and *d d′ d″* are opened, all the others being closed, the cold syrup flows over the serpentines, which are exposed to the open air on the other side of the vessel A″. It is evident that each vessel will produce the same quantity of vapour, since the vaporisation of each of them proceeds from the heat thrown off by

the condensation of the vapours supplied by the preceding one, not taking into account the heat contained in the condensed water, and the loss of heat by the cooling of the vessels. Therefore, supposing that all the vessels contain the same amount of heating surface, the difference of temperature of the boiling in the different vessels will be constant; therefore all will depend on the boiling temperature in the last vessel A″, and on the temperature of the steam from the boiler, if the temperature of the latter was 100°, and the boiling point in the vessel A″ 70°, it would be 80° in the vessel A′ and 90° in the vessel A. If it was only required to be 80° in this latter, the temperature of the steam from the boiler would have an excess of 20°, the temperatures in the vessels A′ A″ would be 60° and 40°; but if the heating surfaces in the vessels A′ and A″ were twice as large as in the vessel A, temperatures of A′ and A″ would be 70° and 60°.

This is supposing the heating surfaces are simply sufficient in each vessel, and as they are always much larger, the surface utilised is variable, and the temperatures of the liquid in the vessels will be much nearer to each other. The temperature of the first vessel will depend on the pressure which remains in the serpentine exposed to the air, on the volume and on the temperature of the vapour supplied into it; and as the temperature of this vapour can be maintained constant by turning more or less the cocks which admit it into the double bottom and serpentine, as well as the quantity of cold syrup allowed to fall on to the serpentine exposed to the air, the effect required can be maintained, either for the duration of the operation, or by the temperature of the boiling in the first vessel. As to the temperature in the others, it is absolutely impossible to determine them; these will be decreasing, and the differences will depend on the area of the heating surfaces and on the temperature of the condensed waters; but this is of no importance, the essential point is to produce a given effect in a given time, the temperature of the syrup in the first vessel being fixed. We will see further on that this arrangement may be applied to three vessels.

It is understood that the apparatus should be arranged in such a way that a vacuum should only require to be formed once or twice a day in the vessels, but at each operation in the reservoirs N and G. The leakage of air

takes place principally through the cocks, which should be very carefully constructed to avoid this.

1651. There would certainly be an advantage in producing and maintaining the vacuum with an air pump, which should communicate with the condensed water receivers and be worked by a non-condensing high pressure expansion engine, the exhaust steam being afterwards used for heating the evaporator; the motive power would cost nothing; we would have a simple apparatus; the air leakages would be immediately stopped; but each condensed water receiver should communicate with the pump by means of a cock, in order to maintain the required pressure in the corresponding vessel, which should be provided with a pressure gauge.

1652. If it was wished to employ different heating surfaces, and only sufficient, the excesses of temperature should be in inverse ratio to the surfaces. Let us suppose three vessels for concentrating, and a fourth for condensing the vapours from the last, let $s\ s'\ s''\ s'''$ be the condensing surfaces, $t\ t'\ t''\ t'''$ and T the temperature of the vapours and that of the water contained in the last condensing vessel, m the weight of vapour condensed per square metre per hour and per degree of difference of temperature; the quantities of vapour produced simultaneously in the three first vessels, and condensed in the following one, will be $m\,s\,(t-t')$, $m\,s'\,(t'-t'')$, $m\,s''\,(t''-t''')$, and that which is condensed in the latter will be $m\,s'''\,(t'''-T)$; all these quantities should be equal, the excesses of temperature *should be constant if the heating surfaces are the same*; if they are different, the excesses of temperature may be easily deduced therefrom; and knowing t, we can draw from it the values of $t'\ t''\ t'''$. As to the quantity of vapour produced in each apparatus, it can be calculated by starting from the value of m, given in No. 1611 and following paragraphs. It is more advantageous to use equal heating surfaces, because then the apparatus will be the same, and an excess of surface is good, in order that the effect is not reduced by the introduction of a small quantity of air.

The above question is of very great importance in all operations where a considerable quantity of water has t be evaporated, as in refineries and sugar factories.

1653. A similar apparatus to Mr Degrand's was constructed in England by John Reynolds, for concentrating

salt water, but it did not succeed. The condensing surface was formed of tubes of small diameter, and heated externally, and became obstructed by crystals of salt. The Multiple Effet apparatus can only be used for the concentration of saline solutions before reaching saturation.

1654. It is chiefly for the concentration of the juices of beetroot that the use of these apparatus becomes important; as the juice contains about 0·08 of sugar, it is necessary to evaporate 92 kilos of water to obtain 8 kilos of sugar; so that each kilo of sugar requires about 2 kilos of coal when evaporation takes place direct.

1655. The principle of successive distillations and evaporation, by using the same heat, appears to have been established and applied for the first time in 1829 by Mr. Pecqueur. Since then, apparatus have been constructed on the same principles in the various manufacturing countries, notably in America by Mr Rillieux in 1845.

1656. In the first arrangements adopted by Mr. Pecqueur in 1829, this engineer made use of apparatus similar to those mentioned in paragraph 1625, so as to allow of the form and length of the tubes being changed without breaking the joints.

In his patent of 1834, the apparatus was arranged as shown in figure 46. The evaporating vessels together form a vertical cylinder open at the top, which is divided into four separate spaces A, B, C, D, by spherical shaped copper plates, forming separate pans. The bottom one is heated by steam, which circulates in the double bottom; pipes with cocks form the communication between one vessel and the succeeding one, so as to allow them to be filled from the lower one by means of the steam pressure, or from the upper vessel by the weight of the liquid; the discharge cocks (only the first is shown in the plan) allow each vessel to be emptied. Below the bottom of each there is a thin copper plate, having the form of an inverted funnel, which

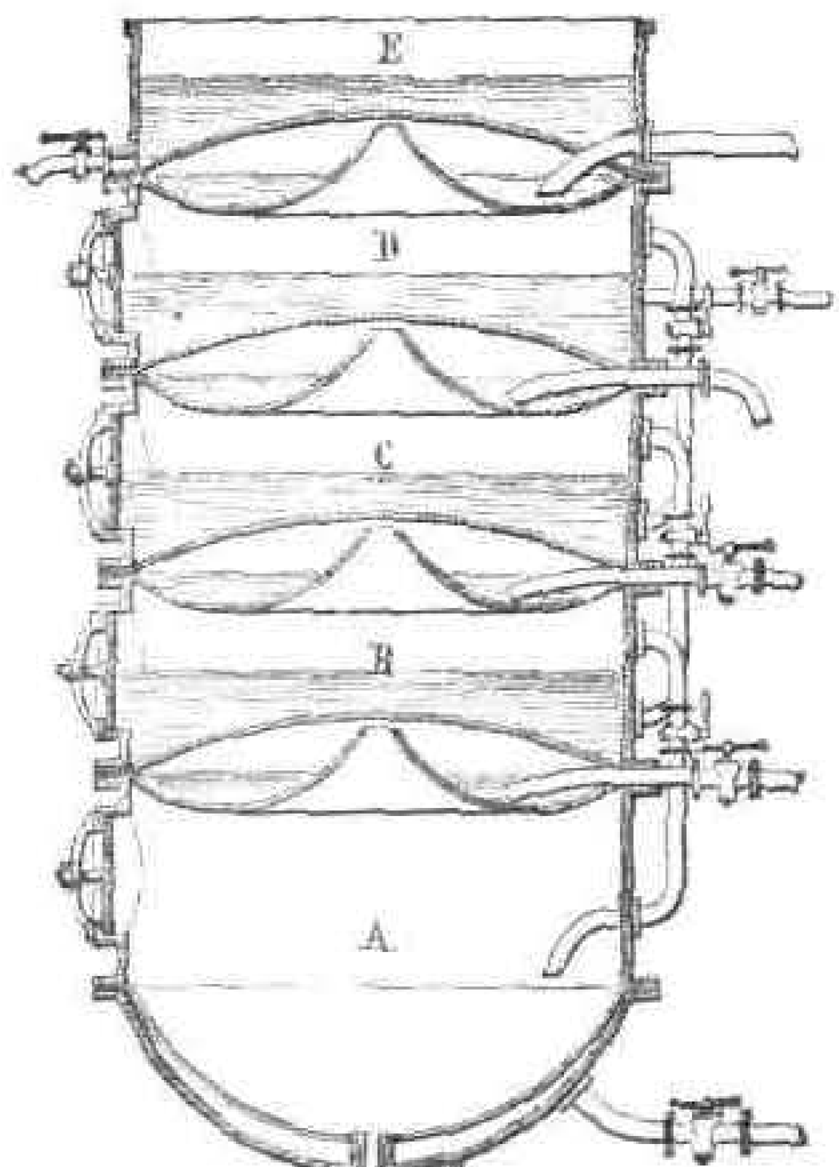


Fig. 46.

is fixed to the sides of the cylinder, falling gradually *from the sides and rising to the centre*, so as to approach very near to the bottom of the upper vessel, at the top of which there is a hole; small copper pipes are fitted near to the lowest part of these plates, and project outside. They are fitted with cocks, and communicate with the space where the vacuum is formed. If we suppose the four chambers A B C D full of the liquid to be concentrated, and the upper vessel E *full of water*, the vacuum formed and steam admitted into the double bottom of the vessel A, boiling will commence almost immediately. The steam will begin to condense on the bottom of vessel B, and the water produced by this condensation will accumulate in the lower part of the double bottom; the liquid in B will come to boiling point, and the same will take place successively in C and D; and after a certain time, the liquid in the vessels A B C D will all be boiling, but at *decreasing temperatures*. This apparatus, the principles of which are very good, leaves much to be desired in respect to details, its principal fault is that there is not sufficient condensing surface.

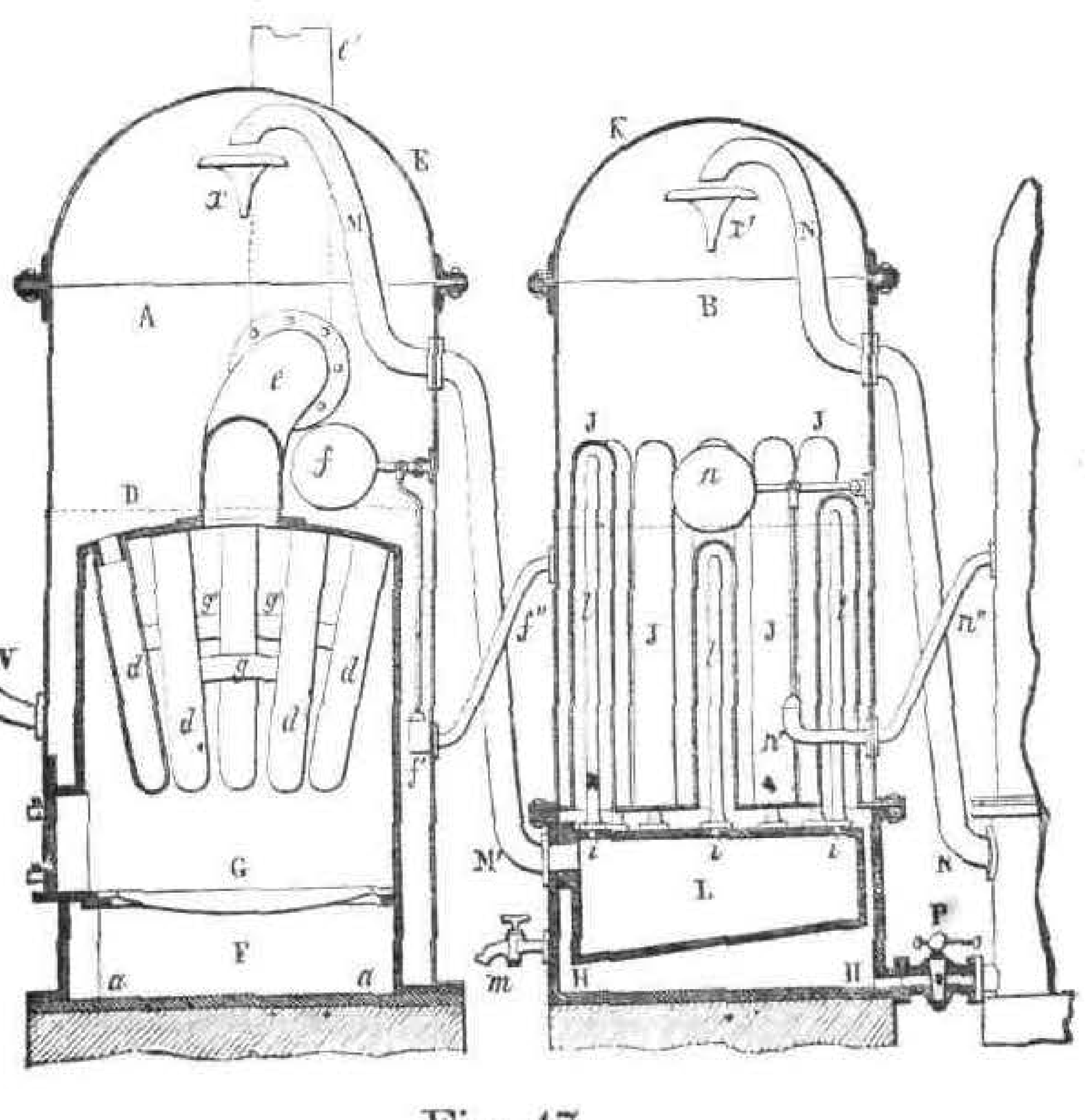


Fig. 47.

1657. In 1848, Mr Pecqueur brought out an apparatus differently constructed, shown in vertical section in figure 47. In order to reduce the size of the drawing, the second condenser is left out, which is identical with the first, and the last only differs from the others in having no dome, so that the liquid in it, which is always pure water, is subject to atmospheric pressure. The following is the description of the apparatus made in the Patent.

"The apparatus consists of a vertical cylinder A, resting on an iron base *a a*, a crown plate D, the top of which is perforated with holes, to which the heating tubes *d d d d* are placed or fitted, these tubes being closed at the bottom and open at the top, a cover E, a chimney *e e'*, an ash-pit F, a furnace G, two partitions *g g' g''* made of fire clay, to make the flame play round the surfaces of the bell and tubes before passing to the chimney, a float *f*, a valve *f'*, and a pipe *f''*. The float, valve, and pipe are for taking the overflow liquid from the boiler to the first concentrating condenser.

"The first concentrating condenser consists of a vertical cylinder B, a cast-iron cistern H H, a plate *i i* pierced with holes, to which are fitted the heating pipes J J, a cover K, a chest L, into which the steam generated in the boiler is admitted through the pipe M M', at the upper part of this chest are fitted as many small tubes *l l* as there are heating pipes J, these tubes rise nearly to the height of the heating pipes, and are open at the ends, a small cock *m* to discharge the liquid deposited in the chest L by the steam, the float *n*, the valve *n'*, and the pipe *n''* are used for carrying the liquid from the first concentrating condenser to the second.

"The second concentrating condenser (not shewn in the figure) is similar to the first, if there was a third or a fourth they would also be similar to the first.

"The covers to the boiler and concentrating condensers are fastened with clasps in place of bolts, so as to be quickly and easily opened and shut, in order that the cleaning may be done in as short a time as possible. To prevent the drops of boiling liquid in the boiler and condensers being drawn into the pipes M M, &c., I place under the openings of these pipes funnel-shaped vessels *x x'* . . .

"The refrigerator is similar to the concentrating condensers, only there is no need of a dome when condensing syrups or distilling spirituous liquors.

"This apparatus may be applied to the continuous concentration of syrups in vacuum. The juice enters the apparatus by its own weight, or by a pump, through the pipe V, which is fitted to the cylinder A, and leaves the apparatus after having passed through the boiler and the first and second concentrating condensers, a certain quantity being concentrated in each.

"The degree of concentration to be given to the syrup is regulated by the quantity of juice admitted to the apparatus.

"When the juice fills the boiler up to the dotted line, the excess raises the float *f*, opens the valve *f*″, and passes into the first concentrating condenser; and when it fills the latter to the height of the float *n*, the excess raises the float, opens the valve *n*′ and leaves the apparatus at *n*″. The result of this arrangement is that the levels of the liquid to be concentrated always remain at the height determined by the position of the floats.

"The fire being lighted, the syrup contained in the boiler begins to boil, the vapour thrown off passes through the pipes M M into the chest L, circulates to the top of the heating pipes J J by the small tubes *l l*, and heats the tubes which heat the liquid contained in the first concentrating condenser; this vapour condenses and falls into the cistern H. The vapour formed in the first concentrating condenser passes through the pipes N N′ into the tank L* and heats the heating pipes J′ J′ . . . . commencing at the top, by means of the small tubes *l′ l′* . . . . This vapour condenses and falls in the form of water into the cistern H′.

"The vapour formed in the second concentrating condenser passes through a pipe into the tank L″, and heats the heating tubes J″ J″, commencing at their top, by means of the small tubes *l″ l″*. This vapour condenses and falls in the form of water into the cistern H″.

"An air pump, in connection with the cistern H″, forms a vacuum in it, as well as in the upper part of the second concentrating condenser. As the pressure is greater in the cistern H, than in the cistern H′, and still greater than in the cistern H″, it is only necessary to open for an

* As already described, the second is identical with the first; the similar parts are indicated by the same letters accentuated. It is exactly the same for the third concentrating condenser.

instant the cock P′, to allow the water and air contained in H′ pass into H″. The cold water goes into the refrigerator at the bottom, and leaves it hot at the top. The discharge of the syrup from the second concentrating condenser, in which a vacuum exists, cannot be made to operate without a suction pump, or two receivers, in which a vacuum can be formed.

"I prefer the use of two receivers, which could be put in communication with the second concentrating condenser alternately, by means of a three-way cock, so that whilst one was filling the other would be emptying.

"Each receiver should have a cock, fitted near the bottom, to empty it. At the top they will be in double communication, firstly, with the upper part of the boiler, by means of a cock and pipe, secondly, with the cistern H″, also by means of a cock and pipe. In order to empty the syrup contained in one receiver whilst the other is filling; it is only necessary to shut the cock in connection with the cistern, and open the lowest cock, also to open the cock in communication with the boiler; the syrup will be forced out by the vapour, and as soon as vapour comes out the receiver is empty. Each receiver should have gauge glasses, in order to see when it is sufficiently filled, so that the syrup will not be drawn into the cistern.

"Such is the apparatus for concentrating syrups by the triple use of the same heat, which will give an economy of about two-thirds of fuel.

"It would only be necessary to add or take away one concentrating condenser to make an apparatus for the quadruple or double use of the same heat, which would economise the half or three-quarters of the fuel."

The general arrangement of this apparatus is well in accord with the physical phenomena which it produces; but from a manufacturing point of view it presents the gravest drawbacks. The first boiler, A, being heated by a naked fire it is almost impossible to clean it, in the others, although in a less degree, there is the same difficulty.

1658. In an American patent granted to Mr. Rillieux in 1845, there is a description of an apparatus for evaporating by the condensation of vapour, constructed according to the principles which we have just been considering. This apparatus resembles a locomotive boiler, only that there are two chests at the ends of the clusters of tubes, one for the vapour to be condensed, and the other for the

condensed water; the space surrounding the tubes is filled with the liquid to be concentrated; the vapour rising from the boiling liquid passes first into the dome of the vessel, then through a large pipe, to circulate through the tubes of the next vessel. The arrangements for circulating the vapour, the liquids to be concentrated, and the condensed water, do not require mentioning here. This apparatus has the same drawback as Mr. Pecqueur's, viz.: the difficulty of removing deposits, the cleaning being by no means easy.

1659. In a patent taken out in 1850, Messrs. Cail and Co. gave a description of a new apparatus, similar to the last one mentioned, but in which the tubes were placed vertically. It does not appear to be an improvement on the first.

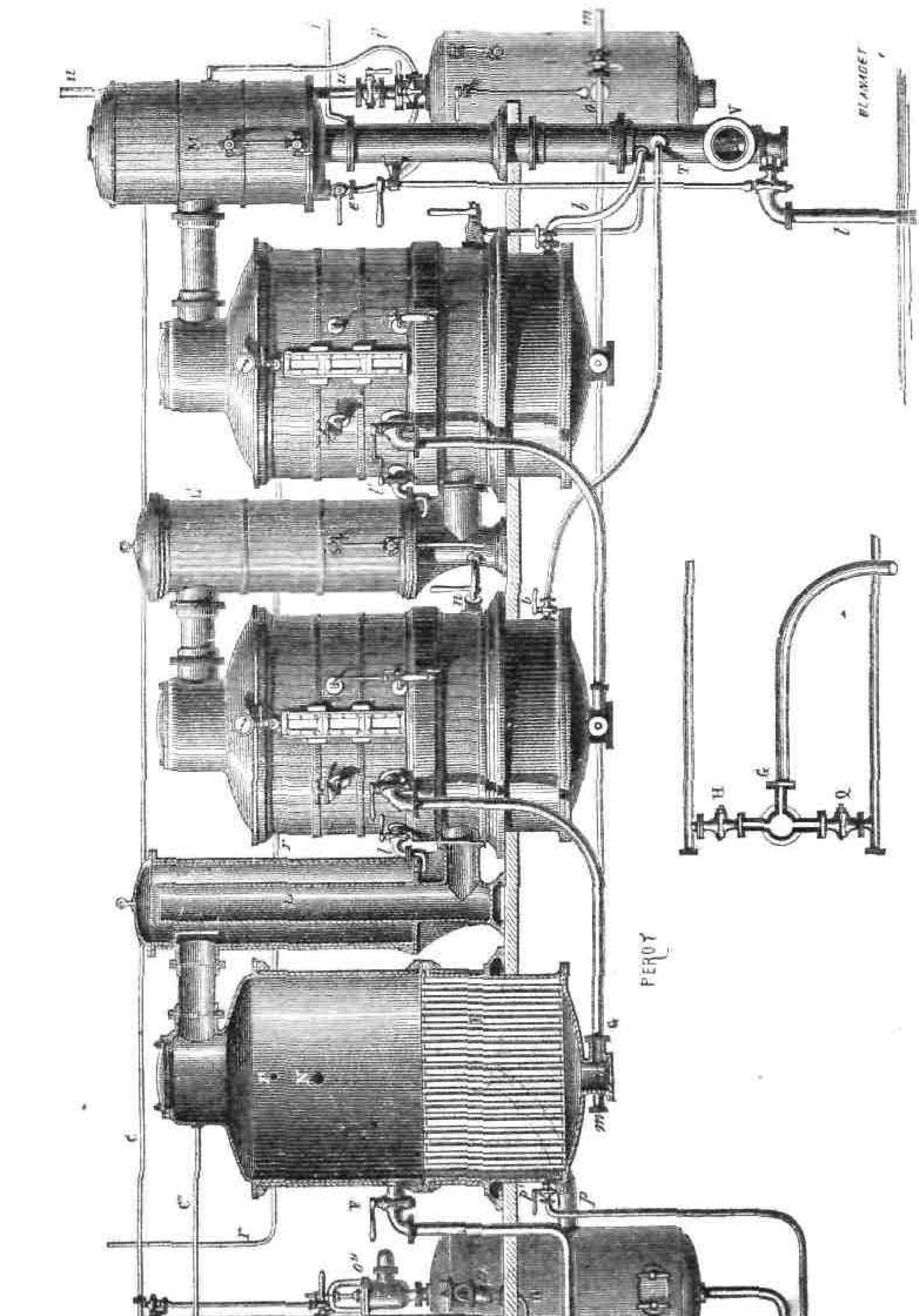
1660. The arrangement adopted by Mr Robert in his sugar factory at Seelowitz, near Brunn (Austria), appears to be preferable. It consists of a vertical vessel divided into three parts by two horizontal partitions, connected by a large number of vertical tubes. The liquid to be evaporated occupies a part of the upper compartment, the tubes all the lower compartment, whilst the vapour circulates between the tubes. Looking at the cost of construction resulting from the number of joints, this arrangement has the same drawbacks as the previous ones, but the interior surfaces of the tubes as well as the vessels, can evidently be cleaned with great ease, and nothing can be deposited on the outer surface of the tubes, as they are only in contact with the vapour.

As to the working, the patents of Mr. Pecqueur certainly contain only ideas which are perfectly just, but the same cannot be said of those which have been taken out since. Thus Mr Rillieux admitted that the vapour condensing surfaces should increase rapidly the further they were away from the first vessel. His apparatus consisted of three vessels, and the vapour produced in the first was condensed at the same time in the two others, which certainly could not take place unless the liquids in these two vessels could commence boiling at the same temperature; nevertheless, Mr Rillieux filled them with liquids of different densities. According to this, the apparatus was really a Double Effet, and only became a Triple Effet when the first vessel was supplied with exhaust steam from a non-condensing high pressure engine, and by calculating the effect of the steam.

These observations apply equally to Messrs. Cail and Co.'s apparatus. According to these constructors, if a first evaporating vessel, heated by fire, or by high pressure steam, boils at 100°, and heats by its vapour a second vessel, and this heats a third, and if the vacuum is maintained in the second vessel at 0·19 metres of mercury corresponding to 65° for boiling temperature, and in the third at 0·70 metres, corresponding to 45° for boiling temperature, and if the heating surface of the first is represented by 1, that of the second will be 5, and that of the third 20. In the first place the effect of the first, if it is heated with flame, cannot be compared with that of the two others, because it depends on the intensity of the fire, which may vary from 20 to 50 kilos of steam per square metre per hour; a comparison could only be made if the heating takes place by steam of a known temperature. As to the two others, the excesses of temperature are 100—65=35° and 65—45=20°; therefore, under these circumstances, the heating surfaces being in inverse ratio to the excesses of temperature, the third surface should be to the second in the proportion of 35 to 20, or 1·75 to 1, and not 20 to 5 or 4 to 1. The apparatus in question is really only a Double Effet, as the vapour from the first supplies both the second and third. Finally, the two last vessels communicating with the air pump by the same pipe, the same expansion is necessarily produced, and the liquids can only commence boiling at the same temperature, and at the same degree of concentration; according to the description, the second vessel could concentrate the syrup to 25° Baumé, and the third would bring it to the crystalising point. It is evident, from what I have just said, that Mr Rillieux, the inventor of the apparatus, has not sufficiently taken into account the physical phenomena produced.

1661. To sum up, it is Mr. Pecqueur who was the first to establish the true principles of distilling and evaporating by Multiple Effet, and who made the first application of it.

1662. At the present time in Germany, they still use Multiple Effet apparatus on Rillieux's principle; the vessels are cylindrical and horizontal, they have horizontal groups of tubes to receive the vapour, the liquid to be evaporated surrounds the tubes, which become encrusted; someone should invent a system to make them removable



Figs. 48 and 49.

in order to allow of them being cleaned. These are the conditions which make the working of these apparatus difficult, or at least troublesome.

1663. In France, they use exclusively vertical vessels with spherical tops and bottoms, and fitted up on Mr. Robert's principles. We give, in figure 48, the usual arrangement of a Triple Effet apparatus on the principles realised by the best constructors.

A, is a reservoir for supplying juice to the first vessel; the juice enters the reservoir through the pipe B, when it is put in communication with the condenser by the pipe C C', on which is fitted a threeway cock D; by turning in a suitable way the cock D, the reservoir is put in communication with the first vessel by the pipe C C', and this vessel can then be filled by means of the pipe M F, to which the cock F is fitted.

The three vessels are arranged in the same manner; in the figure, a section of the first vessel shows the tubes, the others are seen externally. Each vessel is cylindrical in shape and made of cast-iron, having in the inside two horizontal diaphragms made of yellow metal, containing tubes also of yellow metal; the vessel is closed at the bottom by a spherical cover, to which is attached a pipe having several branches, as shewn in figure 49; the branch G conveys the juice through the pipe G F' from the first to the second vessel; the second H is for emptying the vessel in case of accident, and also for carrying the contents through a horizontal pipe *m m'* to the montjus I, which is done by shutting the cock J and opening the cock K. The third branch Q is used for running out the water used for washing, which is admitted through pipe *r*, which branches out from the upper part of the vessel. The pipe attached to the bottom of the third vessel has not the branch G, and the branch H is always in communication with the montjus I, in order to empty this third vessel. The spherical cover which closes the vessel at the top is surmounted by a dome, fitted with a manhole, also a large lateral pipe for conducting the vapours formed in the vessel into a save-all L for the first and second vessel, and into the condenser M for the third.

Each vessel is fitted with a gauge glass, vacuum gauge, grease cock, proof cock, and sight glasses N.

The exhaust steam from the different engines is collected in the receiver O, fitted with a valve O″, to allow the steam to escape, when the Triple Effet does not consume all the steam, and when the temperature exceeds 108°; there is another valve O′ for admitting steam direct from the boilers when the exhaust steam is not sufficient. The steam passes from the receiver O into the first vessel through the pipe *p*, to which a cock is attached; it circulates among the tubes P, and the condensed water flows through the pipe *p*′ into the condensed water receiver, and is pumped from there into the boilers.

The save-all L is divided by a cylindrical partition into two parts, one of which forms an annular space, into which the juice drawn off by the vapour is deposited, and is fitted with a gauge glass, so as to be able to see the quantity of juice drawn into it; it is drawn into the second vessel through the pipe *l*, fitted with a cock; the other part of the pipe L is that which the vapour from the first vessel passes to circulate among the tubes in the second vessel; the excess of vapour can pass through the pipe *n* into the bottom of the save-all L′, which is next to the second vessel; the juice collected in the save-all L′ passes through *l*′ into the third vessel, and the vapour from the second vessel, after going through this save-all, circulates among the tubes in the third vessel; the condensed water flows through the pipes *d d* into the lower part of the condenser. This condenser at the lower part is the same as the save-all; it receives the vapours from the third vessel, the liquid drawn in is drawn out through the pipe *e* by the montjus I, a gauge glass fitted on the condenser shows when this should be done. This condenser is prolonged by a cylindrical pipe T, at the lower part of which the condensation of the vapour takes place; for this purpose, cold water is brought through the pipe *t*, and passes into the interior through a rose *t*′; an air-pump draws the air and condensed water off at the same time, by means of a pipe fitted to the neck V. On the montjus I, the pipe *u* leads the evaporated juice to the tanks; vacuum is formed in the montjus by putting it in communication with the condenser by the pipe *i*′, and pressure is obtained by steam by the pipe *i*.

When the vapour enters among the tubes in each vessel, it helps to form a direct current between the entry and exit, and only a portion of the tubes become heated,

which diminishes the heating surface and consequently the useful effect. Cail & Co. fit in the tubular drum, parallel partitions placed zig-zag, forcing the vapour to traverse successively the whole space occupied by the tubes. The Fives-Lille Co. attain the same end by means of circular partitions, and F. Lebannein and Co., by making the vapour enter a circular belt, fitted round the vessel, as shown in figure 50. The vapour then penetrates through a number of small holes in the belt of the vessel. This contrivance is excellent, and perfectly apportions the vapour over the whole tube surface. The pipe *a* placed on the upper part of the belt communicates with the condenser, according to the inventor this is for withdrawing the ammonia gas which forms during the evaporation of the juice, and which damages the copper tubes; he bases his opinion upon the low density of the ammonia gas, and supposes that this gas will rise to the upper part of the belt, and be easily drawn off by the pipe *a*, this conclusion is not correct; besides, the density of the vapour being 0·622 is sensibly the same as that of ammonia gas 0·596, and the tendency which gases even of different densities, have to mix, is well known; in the case in question, the constant movement of the gases facilitates still more the mixing, and we cannot admit that these gases will separate; the formation of ammonia gas can be prevented by prolonging the boiling of the juices after carbonatation.

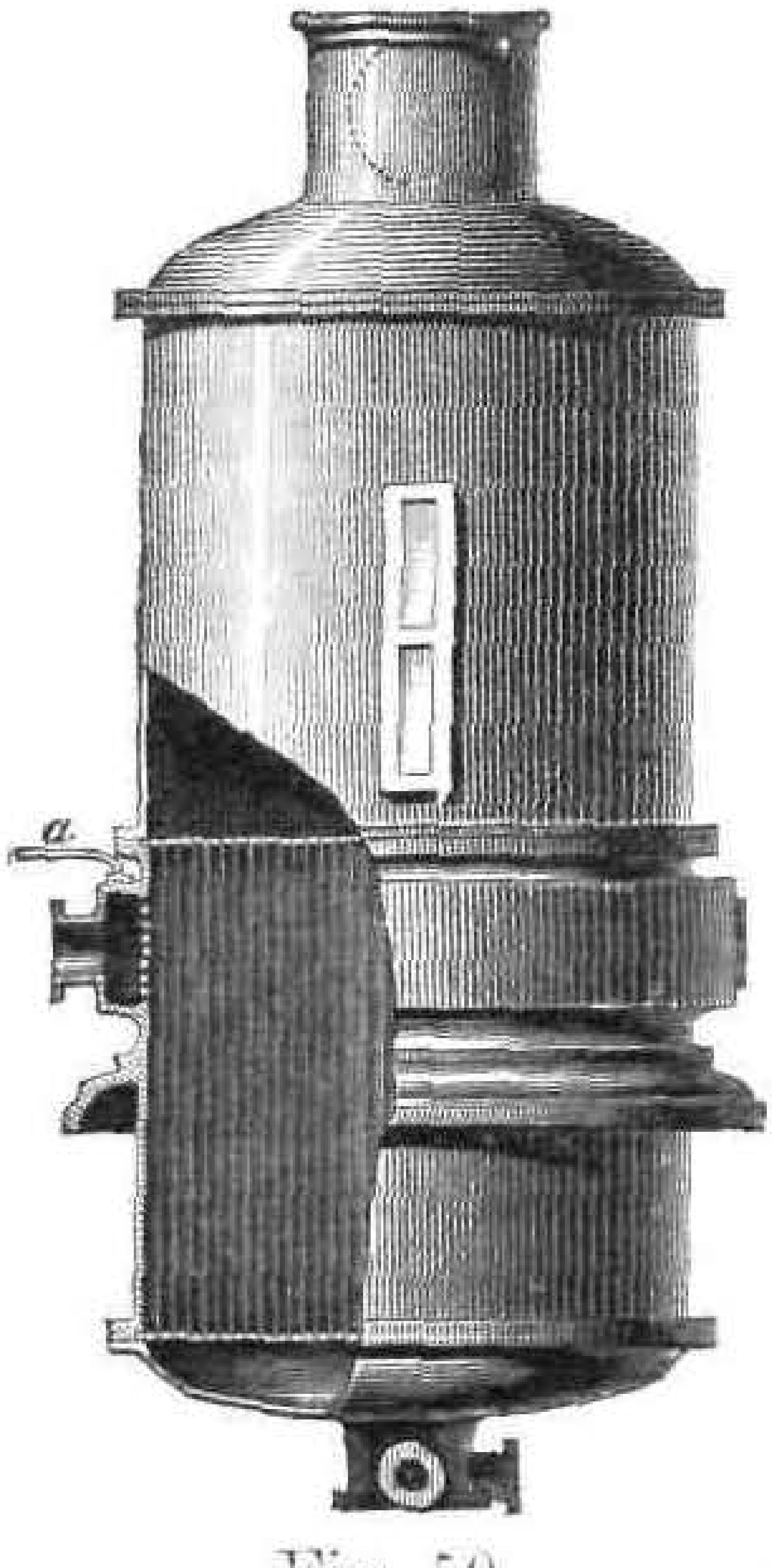


Fig. 50.

The vessels are generally constructed of cast iron, and sometimes of sheet iron with wrought iron tubes. Cast iron cases, at least for those which can treat up to 3000 hectolitres of juice per 24 hours, appear to have an advantage over those made of sheet iron, they also appear to offer more resistance to the causes of deterioration. As to plates and tubes being made of iron, putting aside the rapid

deterioration, it must be remembered that copper transmits heat better than iron.

The following are the proportions of an apparatus for treating 1500 hectolitres of juice per 24 hours. The first vessel has a diameter of 1·38 metres, and contains 340 tubes 1·25 metres long, and 0·045 metre inside, and 0·05 metre outside diameter, having a heating surface of 60 square metres, the height of the body of the cylinder above the tubes is 1·30 metres. The second vessel is 1·52 metres in diameter, 420 tubes 1·25 metres long having a heating surface of 74 square metres, the height of the cylinder above the tubes is 1·40 metres. The third vessel, diameter 1·66 metres, 495 tubes 1·25 metres, heating surface 85 square metres, height of cylinder 1·50 metres; the air pump is 0·41 metre in diameter, stroke of piston 0·50 metre, making 45 strokes per minute.

The steam being at 108° in the exhaust steam receiver, the pressure in the first vessel will be 0·55 metre mercury, and the temperature of the vapour which forms there is 91°; in the second vessel the pressure is 0·35 metre, and the temperature 80°; in the third vessel the pressure is 0·15 metre, and the temperature 60°.

1664. As a rule, 1 square metre of heating surface is allowed per 6½ hectolitres of juice to be worked in 24 hours, to evaporate it from 4° to 20° Baumé.

By the above figures can be calculated the transmission of heat, which takes place through the tubes.

If the density of the juice is 1·047, it will be composed of the following :—

Sugar - - - - - -	8·6	100·00
Ashes - - - - - -	8·2	
Water - - - - - -	83·2	

The result being that 1,500 hectolitres of juice contains 130,351 kilos of water and 13,035 kilos of sugar.

The syrup at 20° Baumé contains :—

Sugar - - - - - -	30·00	100·00
Ashes - - - - - -	2·16	
Water - - - - - -	67·84	

So that the syrup from the 1,500 hectolitres of juice will contain $\frac{13035 \times 67{\cdot}84}{30} = 29{,}546$ kilos of water.

The total quantity of water to be evaporated per 24 hours will be equal to $130{,}351 - 29{,}546 = 100{,}805$ kilos; or 4,200 kilos per hour. There are 60 square metres of heating surface in the first vessel, with an excess of temperature of 17°, viz., $60 \times 17 = 1{,}020$ sq. metres for an excess of 1°; in the second vessel the heating surface is 74 square metres with an excess of 11° or 814 square metres for an excess of 1°; and in the third vessel, the heating surface is 85 square metres with an excess of 20°, or 1,700 square metres for 1° of excess; the total surface will therefore be $1{,}020 + 814 + 1{,}700 = 3{,}534$ square metres for an excess of 1°, consequently the quantity of water evaporated per square metre, per hour and per degree of excess of temperature, will be $\frac{4{,}200}{3{,}534} = 1 \cdot 18$ kilos for the vapour condensed, it is necessary to add to the number 3,534, the quantity of vapour necessary to heat the juice from 10° to the mean temperature of 80° or 70°, and as the weight of the juice is 156,750 kilos, there is required 10,972,500 calories in 24 hours and per 3,534 square metres of heating surface, which gives $\frac{10{,}972{,}500}{24 \times 3{,}534} = 129$ calories per hour, as one kilogram of vapour gives off about 550 calories, the quantity of vapour condensed as surplus will be $\frac{129}{550} = 0 \cdot 23$ kilos; which gives for the quantity of vapour condensed per square metre per hour and per degree of excess $1 \cdot 18 + 0 \cdot 23 = 1 \cdot 41$ kilos.

The consumption of vapour necessary to work the apparatus is composed of two parts:—

1st. That which is necessary to heat the juice; this requires, as has been seen, 10,972,500 calories in 24 hours, or per hour $\frac{10{,}972{,}500}{24}$, and as one kilogram of vapour gives off in condensing about 550 calories, the number of kilograms of vapour necessary for the heating will be $\frac{10{,}972{,}500}{24 \times 550} = 831$ kilos.

2nd. The quantity of vapour necessary for the evaporation; the total quantity of water to be evaporated in 24 hours is 100,805 kilos, and if we take as an approximate that 1 kilo of condensed vapour produced in a Triple Effet apparatus, will evaporate 3 kilos of water, the quantity of vapour necessary for the evaporation in 24

hours will be $\frac{100,805}{3}$, and in one hour $\frac{100,805}{3 \times 24} = 1,400$ kilos; the total quantity of vapour required will be $831 + 1,400 = 2,231$ kilos per hour; this quantity must be taken as a minimum, as the heat lost by radiation of the vessels and conducting pipes, has not been taken into account.

1665. In order to further reduce the consumption of vapour in the manufacture of sugar, the condenser M is sometimes replaced by a combined condenser and juice heater as represented in figure 51. It consists of a cylinder A containing tubes through which the juice flows to the carbonatation, the juice enters at the bottom of the vessel B, at 10° and leaves it at 40° through the branch C at the top, which is encased in an enlarged case D into which the vapour enters from the third vessel of the Triple Effet, the syrup drawn in with it is deposited in the space D, and can be drawn into the montjus through the pipe and cock E. The gauge-glass F shews when this must be done; the vapour circulates amongst the tubes and becomes partly condensed and afterwards goes into the space G, where it comes in contact with the injection water, to which the pipe from the air pump is attached. This arrangement has the double advantage of decreasing the quantity of water necessary for the condensation, and the quantity of vapour required to heat the juice for the carbonatation. The full benefit of this is never obtained unless the interior of the tubes are kept perfectly clean; it is therefore necessary to clean them frequently to get rid of the deposits of lime left by the clarified juice in passing through them; on account of this complication of work very few manufacturers make use of this apparatus.

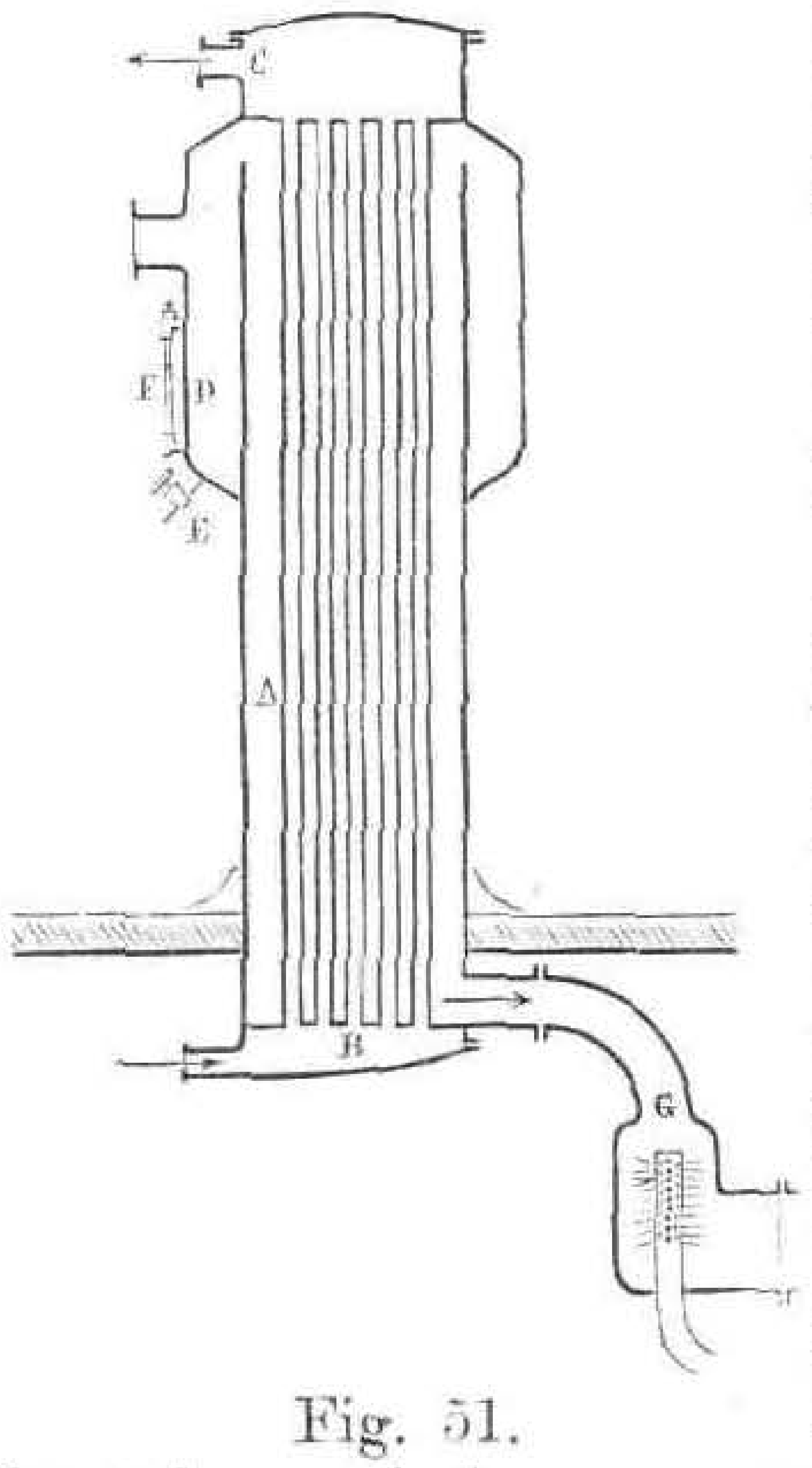


Fig. 51.

EVAPORATION OF LIQUIDS BY USING FOR HEATING PURPOSES, THE EXHAUST VAPOUR, AFTER HAVING BEEN COMPRESSED.

1666. In the preceding pages there has been described the use of the heat of vapour for producing successive evaporations under decreasing pressures. Previous to 1840 Mr. Pelletan propounded another method of evaporation, which consisted in making use of a pump to draw up the vapour generated in a closed vessel, and to compress it, in a double bottom, in such a way as to increase its *temperature; this vapour condenses in producing* fresh vapour in the vessel. If the condensed water, in escaping, exchanged its temperature with the liquid supplied to the vessel, and if there was no loss of heat through the outer casing, it is evident that with the same quantity of heat it would be possible to evaporate an indefinite quantity of water with the aid of mechanical power, but as the utilisation of the condensed water would cause too many difficulties, it may be assumed that it would be discharged at a temperature of 100°, therefore, the expenditure of heat to evaporate 1 kilo of water would only be 100 units instead of 650, and with 1 kilo of direct steam from the boiler $6\frac{1}{2}$ kilos of water could be evaporated. According to Mr. Pelletan, they only used 1 kilo of coal to evaporate 30, and even as much as 100 kilos of water. Evidently that would not be possible unless no account was taken of the power required to drive the pumps, and the condensed water, at least for the last figure, was not discharged at 100°. The mechanical work employed could furnish heat indefinitely, and may theoretically obtain the effect mentioned by Mr. Pelletan. But this work can only furnish its equivalent in heat, and will itself result from the use of an equivalent quantity of heat supplied by a steam engine; we know that the steam engine only returns a small fraction of the equivalent of heat which it has used, and by this we see the failure of such a system. Mr. Pelletan also proposed to produce expansion in the vessel, and the compression of the vapour in the double bottom, by a jet of vapour; it would appear that the first system has never been tried. The following is an account of the ingenious contrivance used for the second system.

M (fig. 52) is a water closed vessel, the cover of which I I is balanced by a counterpoise. This vessel, for concentrating the juices of beetroot, is heated by a double serpentine G G placed at the bottom, A A are pipes for carrying off the vapours formed in the apparatus and are fitted with cocks *a a*; the jets of vapour are supplied through the pipes *b b* from the chests B B, to draw the vapours through the pipes A A, and to drive them into the serpentines through the pipes *c c*, D D are supplementary inlets for the steam to set it in motion; F F reservoirs for retaining the water drawn in by the steam when it comes from the boiler through the pipe E; H the condensed water pipe. It will be seen that, after a preliminary operation, the air is driven from the vessel and all the cocks opened, the jet of vapour escaping through the nozzle *b*, draws the vapour which has been formed in the upper part of the vessel, compresses it by forcing it into the serpentine, the heating is supplied by this vapour and the steam from the boiler. The vessel in which the following experiment was made was 1 metre broad and $2\frac{1}{2}$ metres long. They commenced by discharging the air from the vessel, and heating the water to 100° by admitting direct steam into it; then they admitted steam into the serpentine, and opened the cocks *a a*; the pressure in the vessel F was maintained at 5 atmospheres, and at 0·873 metres mercury in the serpentine. The quantity of water evaporated in the vessel was 91·9 kilos.

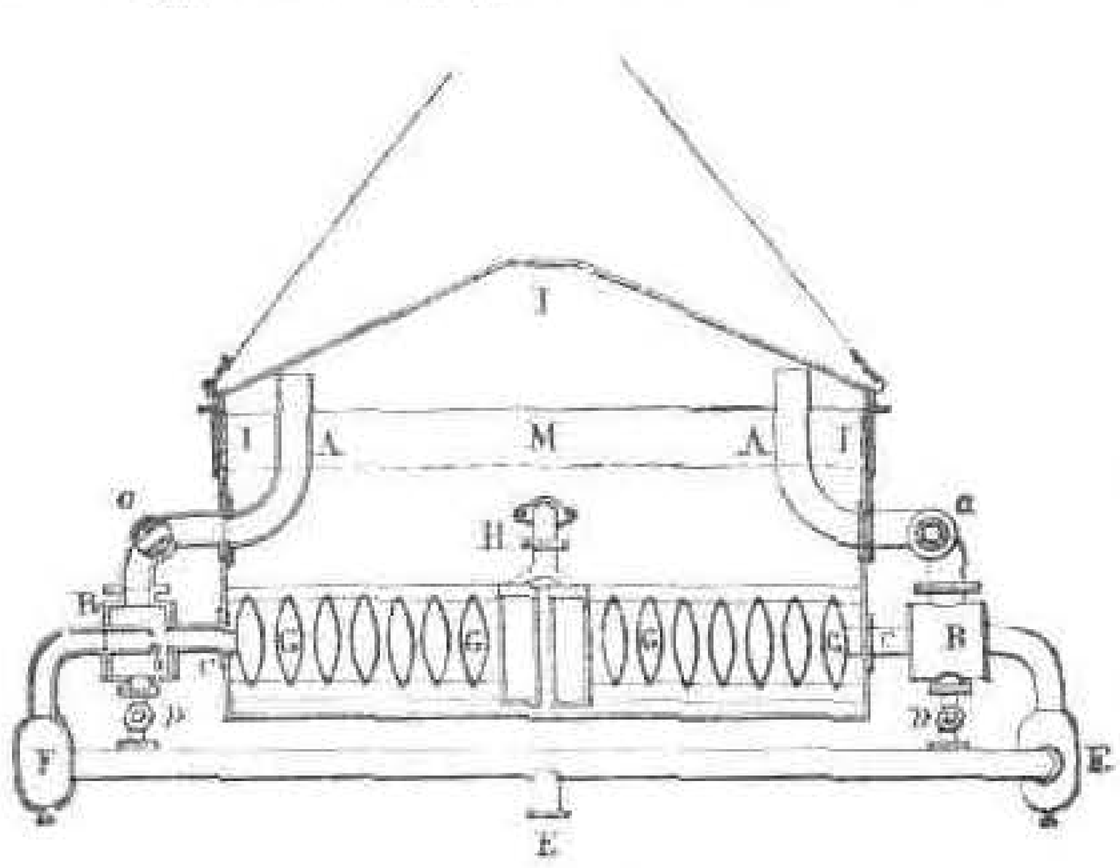


Fig. 52.

In the first experiment 40 kilos of water was condensed in the serpentine. Admitting that the quantity of steam supplied by the boiler was the same in both experiments, it would follow that 40 kilos of steam would have evaporated 91·9 kilos of water, which gives $\frac{91{\cdot}9}{40}=2{\cdot}3$ kilos of water per kilo of steam. The only way to ascertain the effect which this method of evaporation could produce, would be to condense completely the steam at its exit from the serpentine; the weight of the water thus obtained,

added to that of the water which had flowed from the serpentine, would represent the weight of the steam supplied by the boiler, and that of the vapour supplied by the liquid under evaporation, this latter weight could easily be ascertained by the reduced level, the relation of the quantity of steam used to that which is produced could easily be found; until an experiment has been made we can only surmise about the efficaciousness of this method of evaporation. It appears that these trials have not been made, or or at least that the results have not answered to the inventor's hopes, as he has not persisted in his researches. We have only preserved this description of Mr. Pelletan's experiments on account of the use made some considerable time since, of the principle of injecting either for the compression, or the rarefaction of gases.

1667. It is still possible to utilise the heat arising from the condensation of vapours to produce a second evaporation, when the boiling temperature of the second liquid is less than that of the first, there are even cases in which this operation may be executed with extreme facility, for instance, in acetic acid factories, the raw acid obtained by the distillation of the wood, must be distilled over again, in order to separate it from a portion of the tar which it contains, after which it is mixed with lime, and the solution of acetate of lime is concentrated to a certain point, this concentration can be produced by the heat coming from the concentration of the vapour in the distillation of the raw acid; and for this purpose, instead of conveying the vapour in a serpentine it is brought into a lime-wash, the acid combines with the lime and the heat which results from the condensation of the vapours and from the combination, concentrates the solution of acetate of lime. This process was put in practice about 1835 by Messrs. Thomas and Laurens and succeeded well.

Vol. 3. Book XII.

HEATING LIQUIDS.

Liquids can be heated in different ways:—1st. By the direct action of a furnace. 2nd. By steam. 3rd. By circulation. 4th. By exchange of temperature with other liquids. I will treat successively these different methods of heating, and afterwards the heating of water for baths, apparatus for lye-washing, and domestic economy.

CHAPTER I.

HEATING LIQUIDS DIRECT.

2042. I will first recall some of the principles which have already been pointed out. When a liquid is enclosed in a vessel, it can be heated direct by placing it on a furnace and by making the smoke circulate round the outside of the vessel. If the circulation only took place round the sides and above the vessel, the heating would be effected with very great difficulty, as liquids are very bad conductors of heat; they really only heat by the movements which the heat produces. When the heat is applied to the bottom of the vessel, the liquid layers which are immediately in contact with the bottom, and which are heated direct, become specifically lighter than those above, so rise, and are replaced by others, which, after being heated, rise in their turn. It is evidently with the heating of liquids as with evaporation; the capacity of the vessels have no influence on the useful work of the fuel; it is only the surface of the boiler which transmits heat, consequently this is the only element which should be taken into calculation, and in such a way as to bring to the hot air the largest quantity of heat possible.

2043. In order to determine the area of the heating surface, we should make use of the same data as for evaporation, that is to say, to estimate that the quantity of heat which a square metre of surface transmits, is equivalent to that which would evaporate from 15 to 30 kilos of water per hour. As a matter of fact, if the temperature which the liquid should acquire was much below 100°, the quantity of heat which would pass across a similar area of the surface of the boiler, would be greater than if this heat had been used for evaporation, because we have seen that the heat which traverses the metal increases with the difference between the mean temperature of the warm air and that of the liquid, but this difference is only slight, and it is better to have an excess of surface. 1 square metre of heating surface will be taken per 3 to 5 kilos of coal, or 6 to 10 kilos of wood to be burnt per hour.

2044. The surface of the grate, the section of the flues, and that of the chimney will be calculated, the same as for steam boilers.

2045. When the liquid to be heated is volatile, it is *very important to see that the boiler is securely closed, or* at least, to cover it in such a way that the air which is above the liquid cannot easily renew itself, as the evaporation which would take place absorbs a large quantity of heat, and the useful effect of the fuel would be reduced, and the heating retarded. It might even happen, if the area of the surface of the liquid was very large, relatively to the quantity of fuel burnt in the furnace, that the temperature of the liquid would not be able to exceed a certain limit.

2046. All the apparatus which have been described for the evaporation can be used for heating the liquids; but *the simplest apparatus are always used for this latter* purpose.

2047. It is important to note that in heating liquids the heat thrown off can be utilised almost completely by producing a draught by the heat before or during the heating, or by a mechanical action. But in nearly all special cases there are special conditions to fulfil, which will not allow of using the most economical means of heating.

2048. Figures 53 and 54 represent two sections of a boiler for heating water, in which the preceding principles are used.

2049. In former times, for the same purpose, large *tubes were used, with an internal furnace, the door of which*

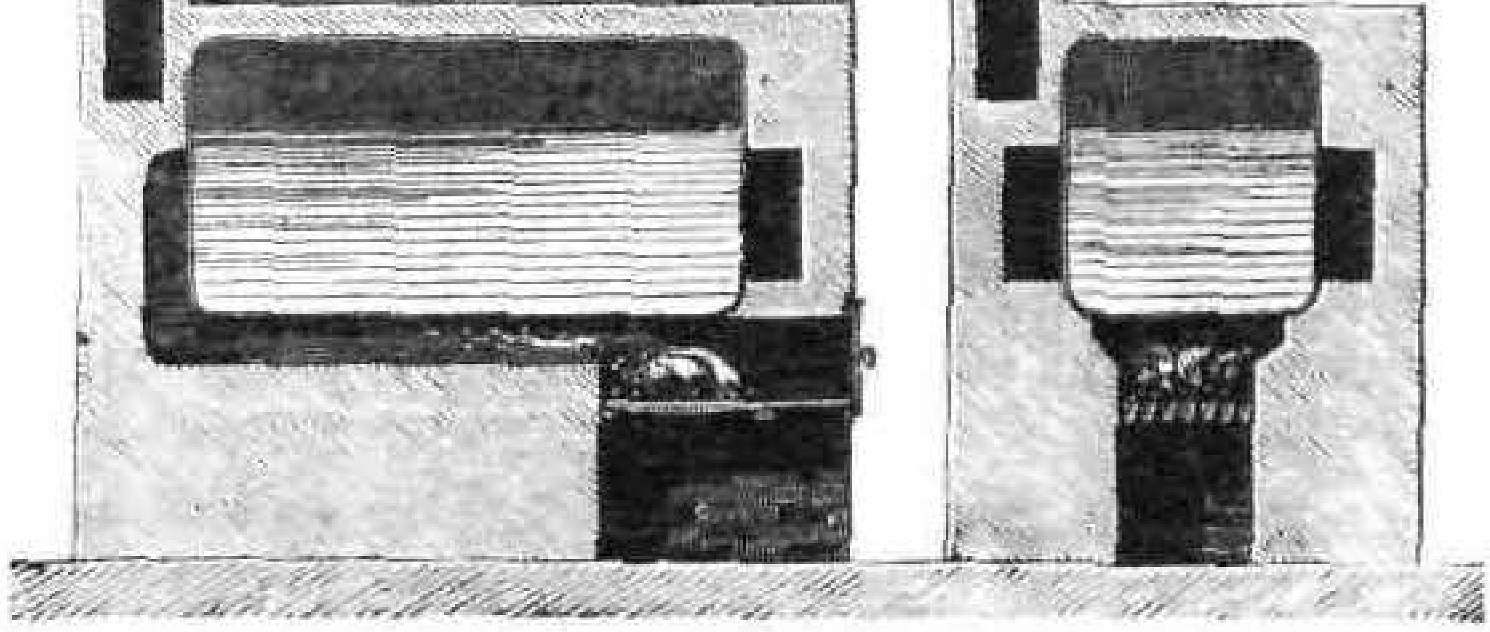


Fig. 53. Fig. 54.

was perforated in front; the smoke rose at first up to the level of the water, and re-descended to rise afresh and *reach the chimney. This arrangement has really no advantage*, as it is very difficult to make the joints of the door tight; this method of heating has also been abandoned, in

spite of the economy of first cost. This system, but with tubes made of copper, is used in small bathing establishments.

2050. In the Vigier Baths, on the Seine, Mr. Darcet established a system of heating the water, in which the whole of the heat produced by the combustion was utilised. The apparatus consisted of a rectangular sheet-iron boiler with two furnaces, heated from below, and traversed by tubes through which the hot air circulated, then ascended into two iron chimneys, communicating at will with a system of small horizontal tubes placed in the cold water tank; at the other extremity these small tubes discharged the hot air into a closed vessel, communicating with a fan driven by manual power, which produced the draught necessary for the combustion, at the same time the hot air was made to circulate through the tubes in the cold water tank. Figure 55 shows an elevation of the two chimneys and a longitudinal section of the rest of the apparatus, and figure 56, a transverse section of the cold water tank. This latter was 20 metres long, 1·30 metres wide, and and 1·20 metres high, containing twelve tubes 0·10 metre diameter.

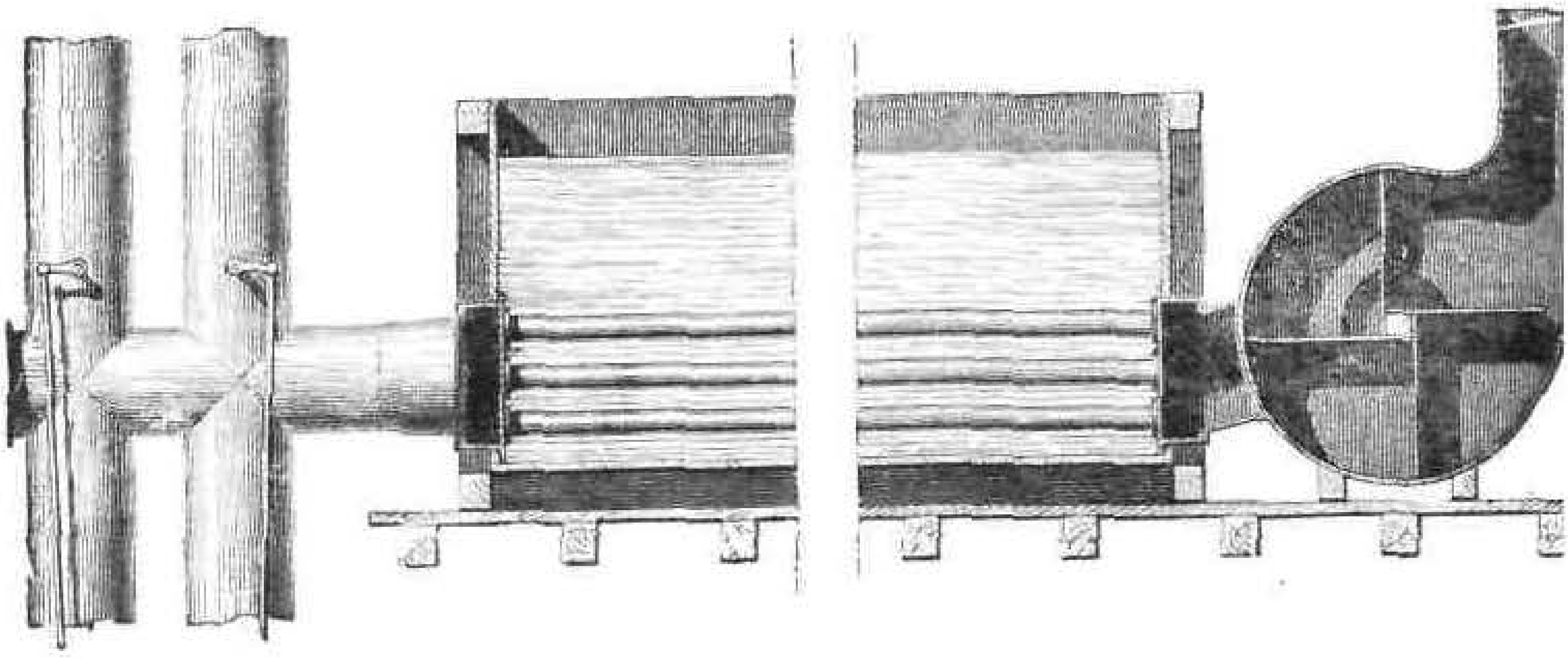


Fig. 55.

2051. In an experiment made very carefully, they burned in two hours 0·53 cubic metre of barked wood weighing 200 kilos, which raised the temperature of 7,180 kilos of water in the boiler to 58·75°, and the temperature of that in the tank, which had three times the quantity, to 8·75°. This effect is equivalent to 7,180 kilos of water raised to 85°, or to 20,343 kilos of water heated from 30°, for 72 baths. The price of the wood consumed being

$0{\cdot}53 \times 17{\cdot}50 = 9{\cdot}27$ fr., the net cost of each bath would be $\frac{9{\cdot}27}{72} = 0{\cdot}13$ fr. It will be seen from these details that by the use of the fan, the useful effect is increased in the proportion of 59 to 85. The arrangement of the furnace was not good, the fires were too small, and so were the flues; the result being that the flame went out very quickly, giving a large quantity of smoke; also the tubes in the cold water tank soon became obstructed with a sticky soot, which was very difficult to remove. The heating surface was sufficient, being 18·60 square metres, per 100 kilos of wood burnt per hour, consequently each square metre corresponded to $\frac{100}{18{\cdot}60} = 5{\cdot}3$ kilos of wood, the whole part of the lower heating surface of the boiler, produced little effect; the section of the chimney was the proper size.

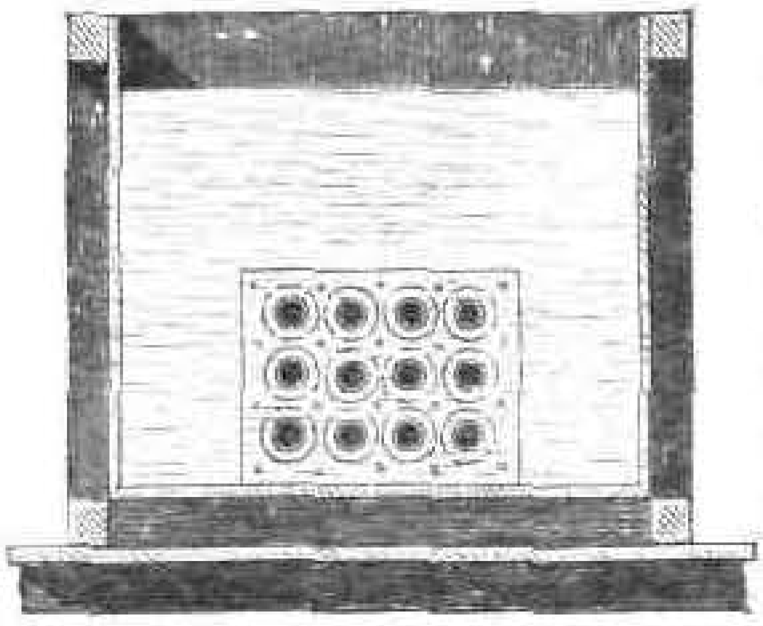


Fig. 56.

2052. In many bathing establishments they have a very simple arrangement, which gives good results. It is represented in figures 57 and 58.

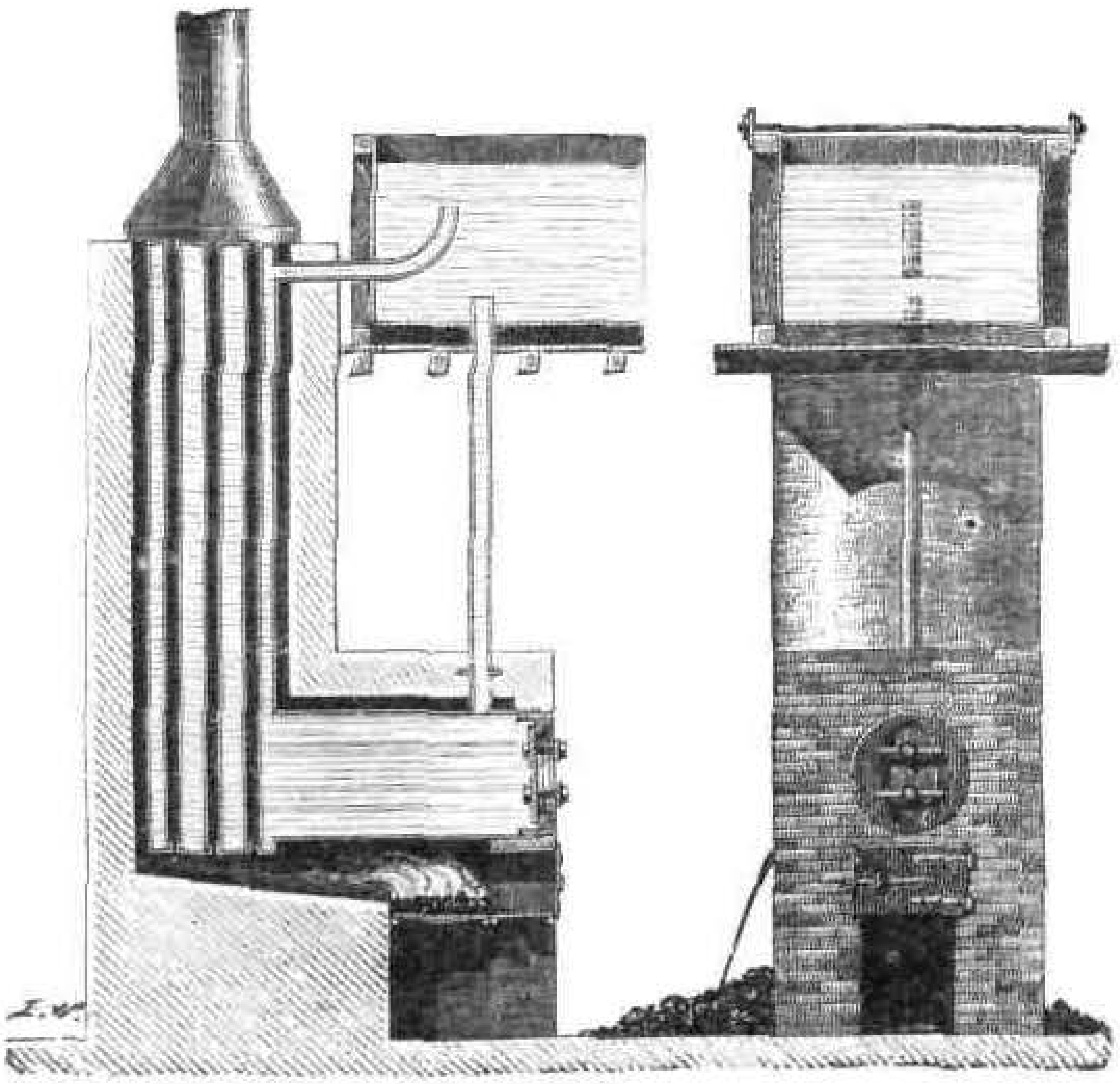


Fig. 57. Fig. 58.

The apparatus consists of a horizontal boiler, connected at one end to a vertical boiler 3 metres high, containing nine vertical copper tubes, fixed in the same way as those in locomotive boilers, and open at both ends. The masonry is so arranged that the hot air surrounds the two parts of the boiler, and can rise simultaneously in the tubes. At the upper end of the boiler there is fitted a cone, made of iron, for conducting the air into the chimney; this can be removed to clean the flues. A tank placed alongside contains the water, which is heated by circulation. The apparatus contains 16 square metres of heating surface, and consumes 10 kilos of coal per hour; the hot air escapes at the upper part, at a temperature of 50° to 60°; the draught is very good, even when the cone on top of the furnace is removed. This arrangement, taking into account the small space occupied, the simplicity of the apparatus, and the effect produced, is superior to the others.

CHAPTER II.

HEATING BY STEAM.

2053. A liquid can be heated by steam in two different ways:—1st. By the condensation of the steam in the liquid itself. 2nd. By the circulation of the steam in a serpentine, or in any other similar contrivance, and immersed in the liquid.

HEATING A LIQUID BY DIRECT CONDENSATION OF THE STEAM.

2054. This method is evidently applicable only when the condensation of the steam is not injurious to the operation; it is principally used in dye works, paper works, baths, &c.

2055. The calculation for the quantity of steam to be supplied in a given time, the dimensions of the boiler, the steam tubes, and all the elements of the furnaces, present no difficulty. Suppose, for instance, that steam at 5 atmospheres is required to bring a series of dyeing vats to boiling point in an hour, each containing 1,000 litres of water at 15°; when the boiling point is attained each kilogram of condensed steam will have furnished the liquid

with $652{\cdot}94-100=552{\cdot}94$ units of heat, whilst the water from the condensation remains in the liquid. Therefore the quantity of vapour to be supplied in an hour will be $\frac{1000\times85}{552{\cdot}94}=153{\cdot}7$ kilos.

2056. In dye and paper works, heating with steam shews to great advantage over direct heating, 1st, because each vat to be heated separately required in the old system a separate fire, whilst in the new, one is sufficient for all, however numerous they may be; this gives a great saving of fuel, as the loss of heat by radiation from furnace sides increases with their number; 2nd, because there is no fear of the matters deposited on the bottom being damaged in heating by steam, as is the case with a direct fire; 3rd, because you can with great ease, by simply working a valve or cock, check the heating and keep the liquid at an even temperature; 4th, because the vats may be of wood, and placed arbitrarily in any part of the works.

2057. The arrangement generally used for heating by steam consists of a vertical pipe going to the bottom of the vat, open at the bottom, the upper part being connected to a steam boiler; to prevent the noise which sudden condensations of vapour occasion by this arrangement, as well as the great oscillation of the water in the pipe, which under certain circumstances, might make it return into the steam boiler, there is usually fitted at the bottom of the vats, a copper pipe, shaped according to the form of the apparatus, the lateral parts of which are perforated with a large number of small capillary holes, this

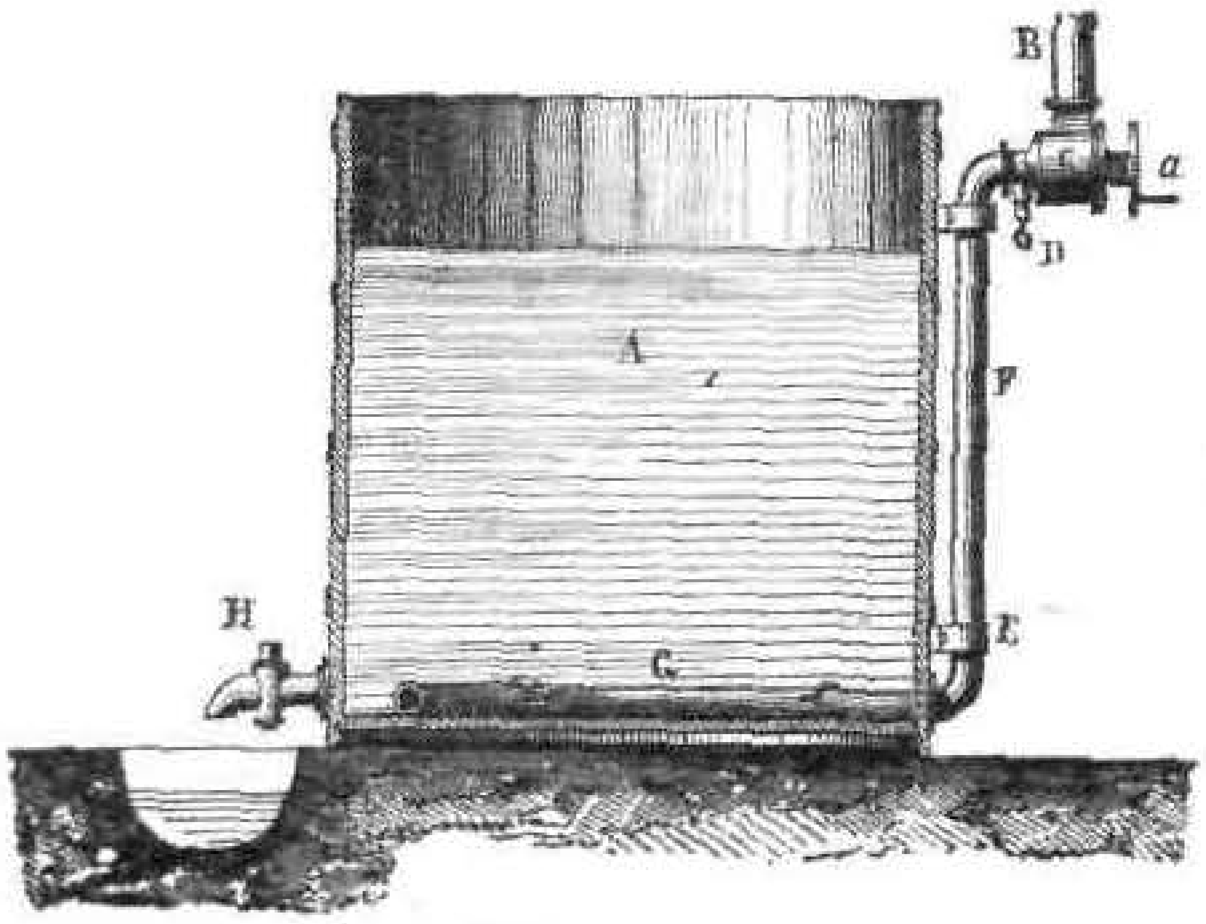


Fig. 59.

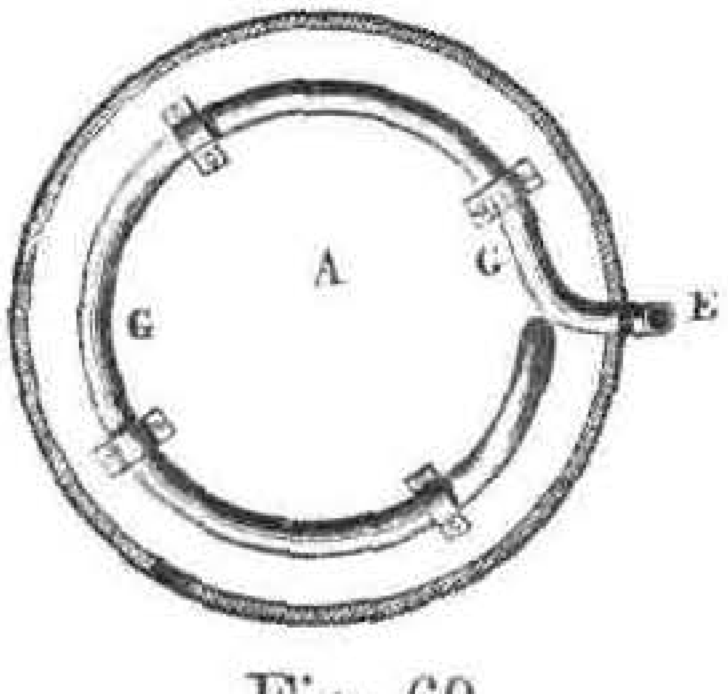


Fig. 60.

pipe communicates with another outside, which supplies the steam from the boiler, and is fitted with a cock, and usually with a small air valve for preventing the movement of the water from the vat towards the boiler.

Figures 59 and 60 show the usual arrangement. A the circular vat; B pipe communicating with the boiler; C stop valve, which is controlled by working the handle *a*; D air valve; E F lateral pipe communicating with the internal pipe G G, closed at the end, but perforated at the lower part, and on one side by a number of capillary holes; H discharge cock. A similar arrangement is applied to rectangular vats for passing the liquid to the dye vats.

2058. The steam supply pipe is placed outside of the vats; first, because if it was placed in the inside, it might be in the way during the operations; in the second place, because the steam which would condense in this pipe would heat that portion of liquid which surrounded it, more than the remainder, and this inequality might cause trouble. It has been noticed that the holes through which the steam passes increase in size by nearly two thirds in two years, and narrow slits were made instead, but the pressure of the steam pressed out the edges, and the pipes were soon past service.

HEATING LIQUIDS BY INDIRECT CONTACT WITH STEAM.

2059. This method consists in allowing the steam to *enter a serpentine, or similar contrivance, immersed in the* liquid to be heated, or in a double bottom. The apparatus are exactly the same as those which we described in speaking of evaporation by heating with steam. The only difference is that the currents of air above must be avoided which would prevent evaporation and cause a loss of heat.

When it is necessary to bring the liquid to 100°, or in case of need to a higher temperature, high pressure steam should be used. All the calculations which have been made for evaporation are applicable to the simple heating, so that it is only necessary in order to determine the quantity of heat required in a given time to multiply the specific heat of the liquid by its weight and by the increase

of its temperature. The heating surfaces should be calculated on the basis that 5 to 7 kilos of vapour are condensed per square metre per hour for a difference of temperature of 1° if it is a serpentine, and 1 to 3 kilos if the apparatus is not arranged in such a way as to entirely expel the air. Whatever the arrangement may be, it would be advantageous to maintain the pressure in the condenser, by means of a pressure regulator.

2060. In the manufacture of sugar they use for the carbonatation of the limed juices square iron tanks, into which the juice is supplied cold, and brought to a temperature of 70°. A tank which can treat 40 hectolitres at each operation, is 1·40 metres high and 2·40 metres wide, and fitted with a copper serpentine, formed of three coils 1·95 metres diameter, the pipes of which are 0·10 metre diameter. The steam is supplied to them at 5 atmospheres, the condensed water discharges into a German condensed water receiver, the heating takes about 15 minutes. It is easy to determine the quantity of steam necessary to produce the heating and that which is condensed per square metre per hour and per degree of mean excess of temperature.

The 40 hectolitres of juice which constitute the charge of the tank requires to raise it from 10° to 70° a quantity of heat equal to 240,000 calories, the heating lasting a quarter of an hour, the quantity of heat required for one hour will be 960,000 calories, which at the rate of 550 calories per kilo of vapour condensed, would give 436·3 kilos of vapour for each operation, or 1745·5 kilos per hour.

The heating surface of the serpentine is 5·76 square metres, and the mean excess of temperature 112°, so that the quantity of heat required per square metre per hour will be equal to $\frac{960{,}000}{5{\cdot}76 \times 112} = 1{,}488$ calories, and the quantity of vapour condensed per hour per square metre of heating surface and per degree of mean excess of temperature will be $\frac{1{,}488}{558} = 2{\cdot}70$ kilos, these figures can only be considered as the minimum, as the heat lost on the sides of the tank and by evaporation on the surface of the liquid have not been taken into account.

CHAPTER III.

HEATING BY CIRCULATION.

2061. This method is shewn in figure 61. The boiler is placed alongside of the vessel to be heated, the upper and lower parts of the two vessels communicate by pipes furnished with cocks. The circulation takes place as in

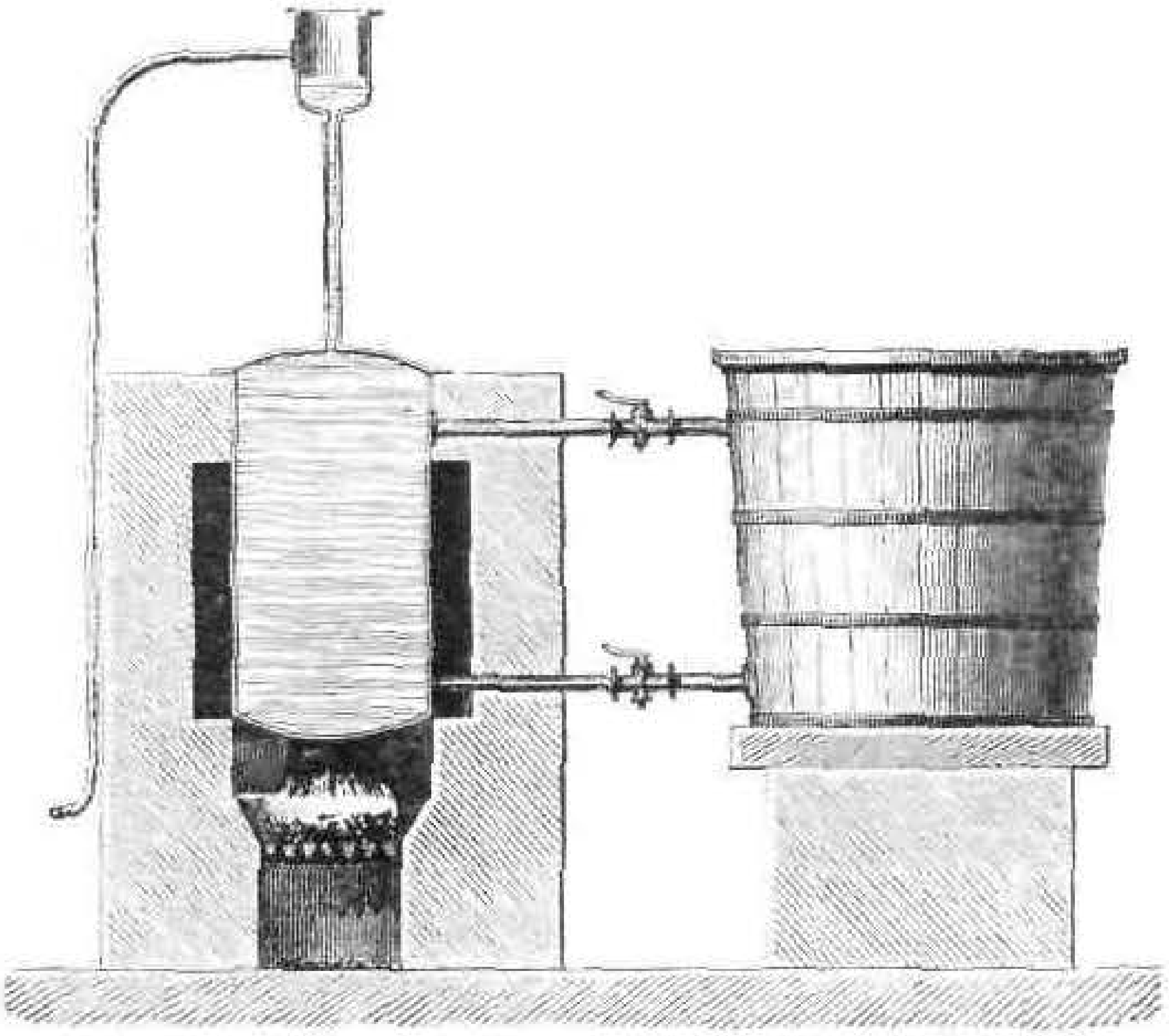


Fig. 61.

hot water stoves. Several vessels could evidently be heated by the same boiler, and the cock would regulate the partial currents which circulate in them.

2062. A liquid can also be heated by the circulation of another liquid, as shown in figure 62. The apparatus consists of several vessels, each containing a serpentine, the

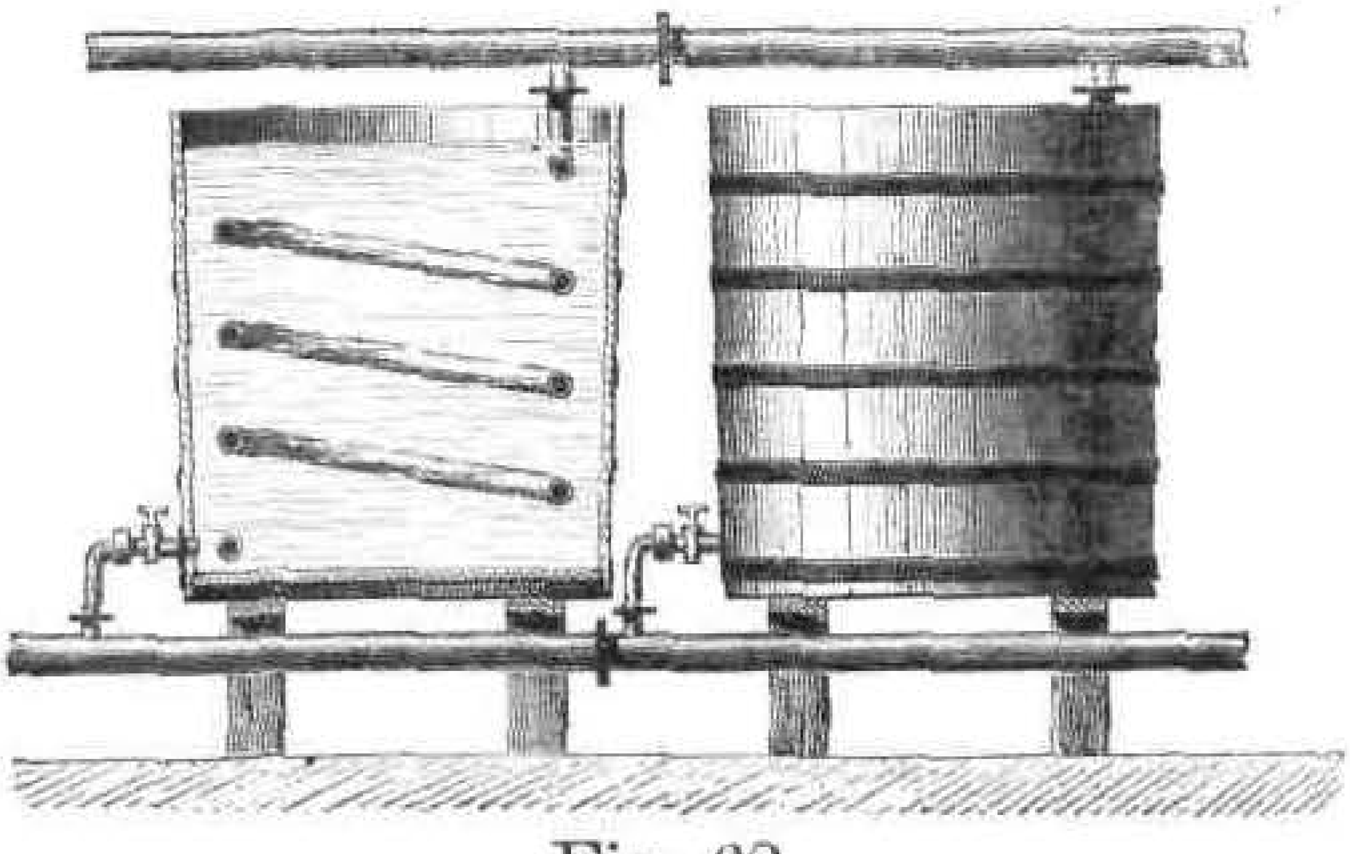


Fig. 62.

ends of which are connected at the top and bottom to pipes, and transmit the heat to the liquids contained in the vessels.

CHAPTER IV.

HEATING A LIQUID BY EXCHANGE OF TEMPERATURE WITH ANOTHER LIQUID.

2063. *This method may be advantageous in some* industries, as it permits of utilising the heats of liquids which become useless and are allowed to escape at a high temperature, and that which comes from liquids when cooling, the temperature of which will necessarily be lowered.

2064. Two liquids at different temperatures, contained in the same vessel, but separated by metal partitions, will in course of time take the same temperature. If we designate by P, c, and t, the weight, the caloric capacity, and the temperature of the first, P′, c', and t' for the same quantities in the second, and Θ the final temperature common to all, *not taking into account the loss of heat* on the surfaces of the liquids and the vessel; the heat contained in the liquids will not have changed, and we have

$$Pct + P'c't' = \Theta\ (Pc \times P'c') \text{ which gives } \Theta = \frac{Pct + P'c't'}{Pc + P'c'}.$$

2065. *It would be the same if the liquids having no* chemical action one on the other, were mixed. Supposing *that the liquids were the same,* $c = c'$, *it gives* $\theta = \dfrac{Pt \times P't'}{P + P'}$ if the two weights are equal, it gives $\Theta = \dfrac{t + t'}{2}$, it will be seen that the heat is always apportioned between the two liquids according to their weight and caloric capacities, the heat of one will never be able to pass completely into the other; but the same does not apply when the two liquids move in an opposite direction and remain in contact with the same metallic partition.

2066. Let us consider two vessels, one containing water at 100°, the *other*, water at its usual temperature, and that the liquid of the first runs through a long pipe of small diameter, and that of the second through a

pipe surrounding the first, but running in the opposite direction, also that the orifices through which the liquids run, are each provided with a cock for equalising the quantities of liquid running at the same time, and that the outside pipe is covered with a material which is a non-conductor of heat, so that it is not necessary to take into account the heat lost by its surfaces; it is evident that, if the areas of the pipes are not too large and their length is sufficient, the velocity of the flow can always be regulated in such a way that there would be a complete exchange of temperature, as the liquid to be heated always encounters in its passage the hot liquid at a higher temperature. It is necessary that the pipes have only a small area, in order that there should only be a slight difference of temperature at the various points of the transverse edges.

2067. If the two liquids are of different caloric capacities, to have complete exchange of temperature their weights should be in inverse ratio to their caloric capacities. If the value of $P' c'$ of the liquid to be heated were greater than that of $P c$ of the liquid which cooled, the cooling would be more complete, but the temperature acquired by the liquid to be heated would be lower than that of the hot liquid; if it were the opposite, it is evident that the cooling of the hot liquid would not be complete.

The principles which we have just enunciated have long been known. It appears that the first application of them was made by Nickols, who applied it to the refrigerator for use in breweries; this was prior to 1824.

2068. Instead of the liquids flowing in opposite directions in concentric pipes or similar arrangements, the hot liquid may flow through a series of vessels containing serpentines, through which the liquid to be heated would flow in the opposite direction; in each vessel the two liquids would sensibly take the same temperature; the exchange of heat would never be complete, but it would approach it more and more as the number of vessels increased. This method would have this advantage, that the deposits which might be formed by the hot liquid could never retard the circulation, and they could be easily removed. Suppose for instance, that the two liquids have sensibly the same caloric capacity, that T is the temperature of the hot water, t the temperature of the cold water, and

that the volume of liquids flowing at the same time is equal. If there is only one vessel the temperature of the two liquids will be $\frac{T+t}{2}$.

2069 If there are two vessels, we designate by T T′ T″ the temperatures of the hot water as it enters into the first and second vessels, and its discharge from the last by $t\, t'\, t''$, the temperatures of the cold water as it enters into the first and second vessels, and its discharge from the last, would give as follows :—

$$t''=\frac{T+t'}{2}\ ;\ t'=\frac{T'+t}{2};\ T'=t''\ ;\ T''=t';\ \text{and}\ t''=\frac{2T+t}{3}$$

If there were 3 vessels it would be—

$$t'''=\frac{T+t''}{2}\ ;\ t''=\frac{T'+t'}{2};\ t'=\frac{T''+t}{2}\ ;\ t'''=T'\ ;\ t''=T''\ ;\ t'=T'''\ ;$$

$$\text{and}\ t'''=\frac{3T+t}{4}.$$

2070. *The same result will be found for 4, 5, 6, or 10* vessels, the temperature of the hot water discharged from the last vessel would be—

$$\frac{4T+t}{5}\ ;\ \frac{5T+t}{6}\ ;\ \frac{6T+t}{7}\ \quad .\ \ .\ \ .\ \ .\ \ .\quad \frac{10T+t}{11}.$$

Supposing $T=70°$, $t=15$, for

1, 2, 3, 4, 5, 6, or 10

vessels, the temperatures of the water heated would be

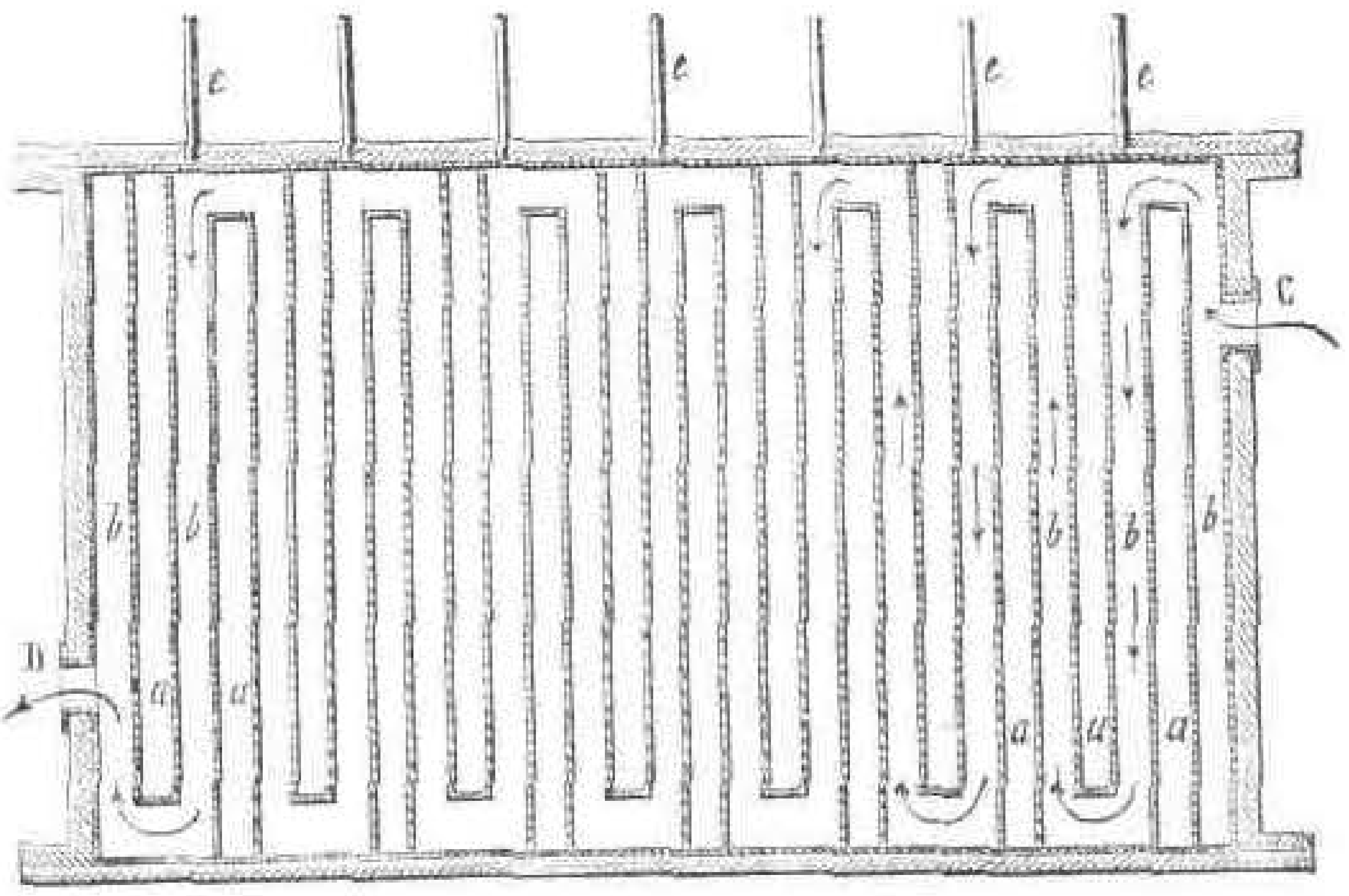
42·50° ; 51·6° ; 56·25° ; 59·00° ; 60·83°; 62·00° ; and 65°.

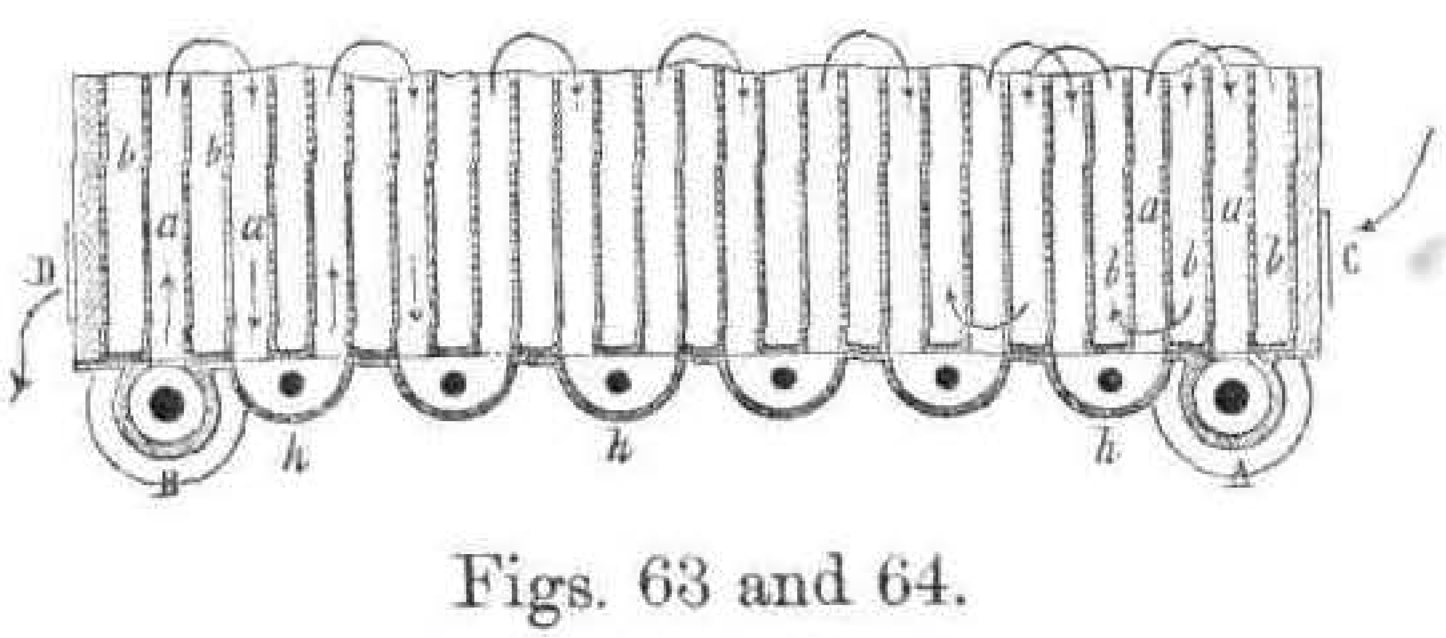
2071. When the apparatus are made for the purpose of producing an exchange of heat between two liquids which form no deposits during the circulation, they can be arranged in a number of different ways. The most advantageous would be those containing the fewest joints, in which the circulation caused by the variations of temperature could take effect freely. If the circulation took place vertically, it would be necessary to supply the culminating points with small pipes for the escape of air. It is impossible to determine beforehand the area which the transmitting surfaces should have, in order that the exchange of temperature between two known liquids should

take place in a given time; the phenomena are too complicated, not only to be calculated, but simply assimilated to those which are produced in heating liquids by steam; the duration of the exchange is never a very important condition provided that it does not exceed a certain limit which otherwise could be foreseen by experiments made on a small scale.

2072. In breweries the malt after being boiled should be promptly cooled. This operation is often carried out in vats made of wood or metal with a large surface in which the liquid only rises to a height of say between 0·10 metre to 0·20 metre, the cooling is caused by the evaporation, radiation, and heating of the air. In order to urge the cooling a current of cold water is often made use of. Water refrigerators are also often used, fitted up in such a way as to produce an exchange of temperature, which allows the heated water to be used for useful purposes. I will only speak of these latter apparatus; the others will only be examined when the question of cooling arises.

2073. Nickols' apparatus is the oldest; it is formed of three concentric pipes. The malt passes between the





Figs. 63 and 64.

outside pipe and the one next to it, the water between the one in the inside pipe. It is very efficacious; but it takes up a great deal of room and cannot easily be cleaned.

2074. *Figures 63 and 64 represent a vertical and* horizontal section of a refrigerator by Schiers and Son, which was much used in English breweries twenty years ago; *a*, *a*, *a*, are channels closed above and below, which one of the two liquids runs through successively, in the direction shown by the arrows. The rectangular channels *b*, *b*, *b*, are separate from the others and closed laterally, through which the other liquid runs, but in a vertical direction to that of the other liquid, so that in the first circuit the velocities are horizontal, and successively in the opposite direction, whilst in the second the velocities are vertical, *and successively from bottom to top and from top* to bottom. The outer case is made of sheet iron, the interior partitions of tinned copper. The malt enters at B, A its discharge, C the cold water supply, D its discharge, *h h* the connections between the horizontal channels, *e e* air escape pipes placed at the upper part of the vertical channels. An apparatus 1·55 metres wide, 2·80 metres long, and 0·84 metres high, contains 80 square metres of cooling surface. According to Mr Lacambre, who had *one erected in the large brewery at Louvain, they cooled* in two hours to 22°, 120 hectolitres of boiling malt, with 200 hectolitres of cold water at 65°. This apparatus has the advantage of combining a large heating surface in a small space; but it is difficult to clean, as all the *h*, *h*, *h* pieces have to be taken off, requiring much time and care.

2075. Figures 65 and 66 represent a vertical and horizontal section of an apparatus used in English

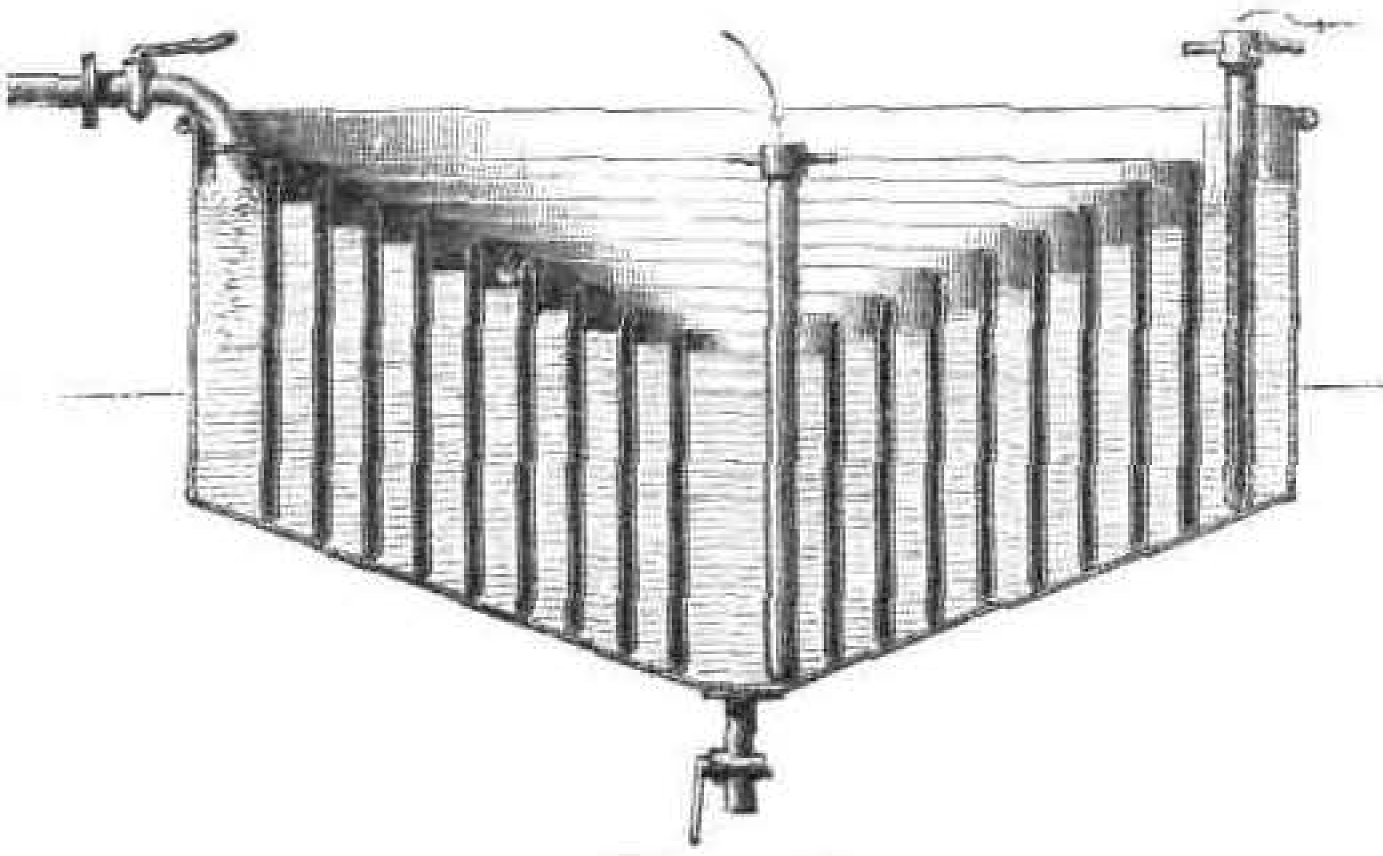


Fig. 65.

breweries, which has not the inconvenience which I have just described. It consists of a serpentine bent spirally, of rectangular elongated section, placed in a copper vessel; the serpentine is traversed by the water, and the space by the malt, but going in the opposite drection. To make use of this apparatus the cock for the entry and exit of the malt must be regulated in such a way that it fills the space between the serpentine. It can be easily cleaned without deranging any part of it, and if necessary the serpentine can be removed, so that it is much more simple than the preceding one, and in every way preferable.

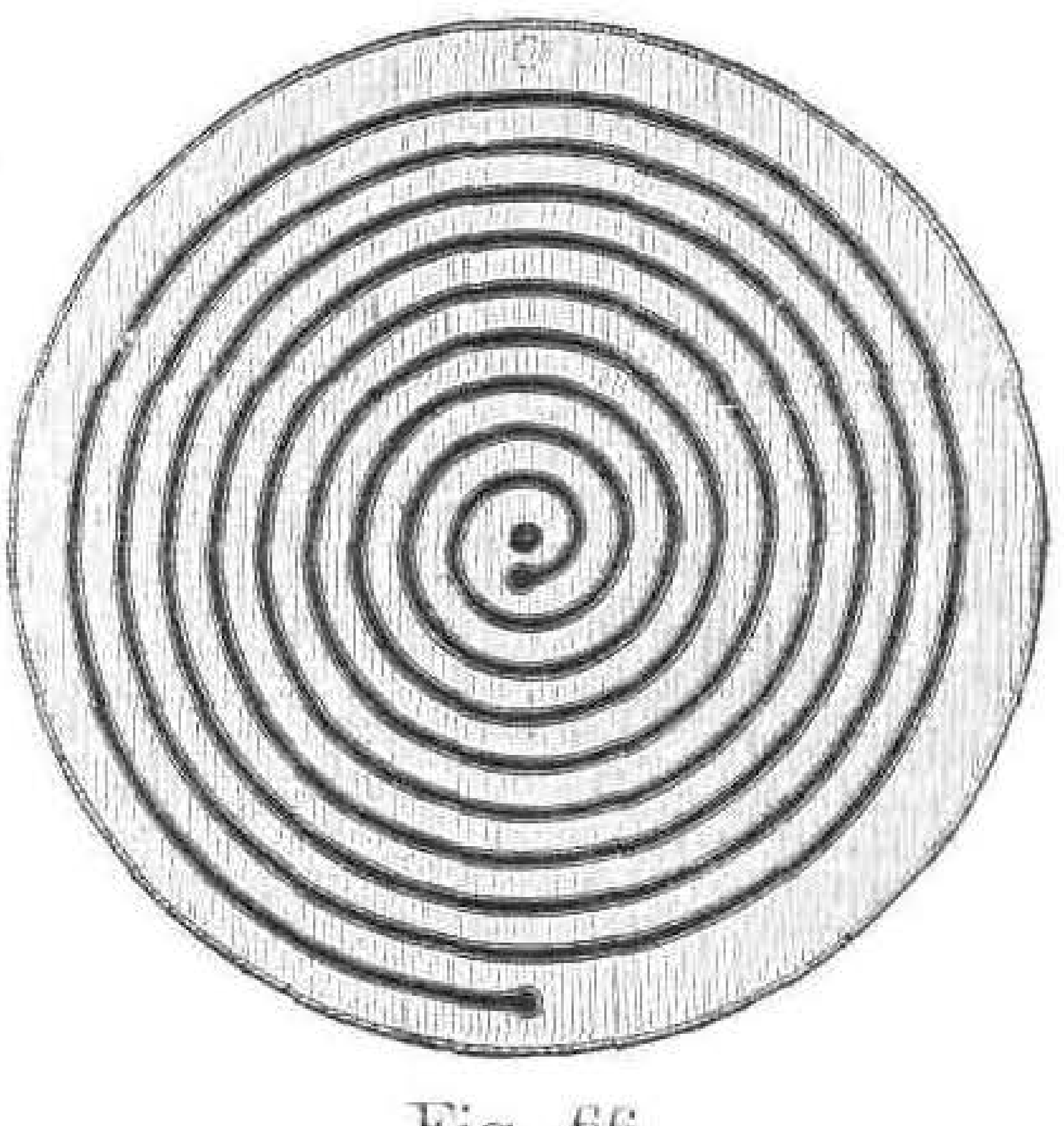


Fig. 66.

2076. Mr. Lacambre's work on the manufacture of beer, from which we have quoted the preceding details, also contains the description of another apparatus which is used in several English breweries, and notably in that at Windsor. Fig. 67 represents the plan of the apparatus, *a a a a* copper reservoir fitted with vertical plates *b b* to compel the malt to follow the course of the serpentine *c*.

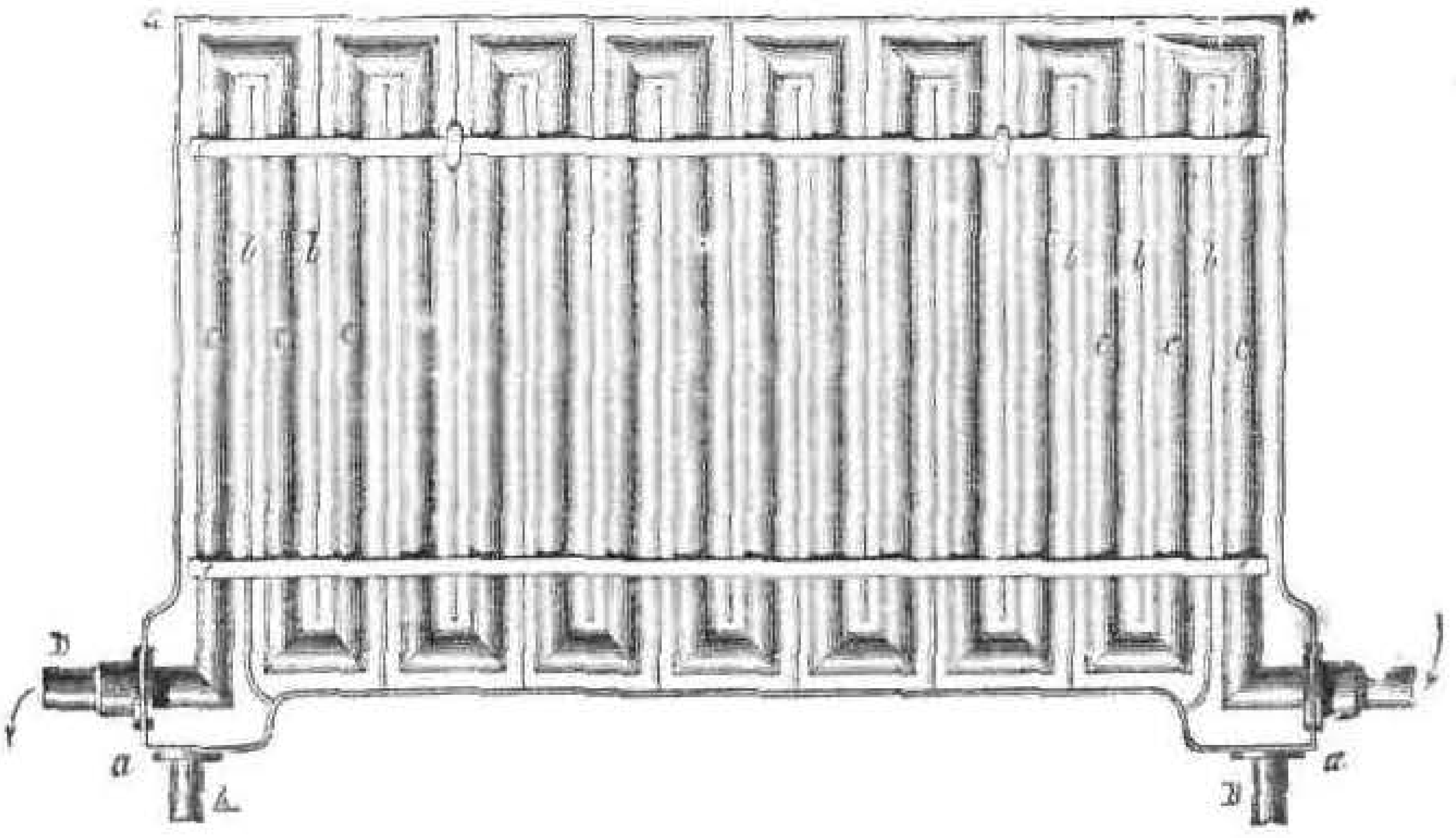


Fig. 67.

A and B supply and discharge of the malt; C and D supply and discharge of the water. The serpentine consists sometimes of a cylindrical pipe or a single flattened pipe of rectangular section. By taking off the ends C and D it is easy to take the serpentine *e* out of the tank in which it is fitted.

2077. Figure 68 represents a vertical section of the apparatus invented by Mr Pimont, of Rouen, which he has applied to dye works. A A rectangular tanks, made of thick wood; B B valves for discharging the cooled water; C water supply pipe from the worked-out baths into the first vat; D supply pipe from the lower part of each tank to a certain height in the next; E pipe for discharging the water from the baths to the outside when they are cooled; F cold water supply pipe; G G serpen-

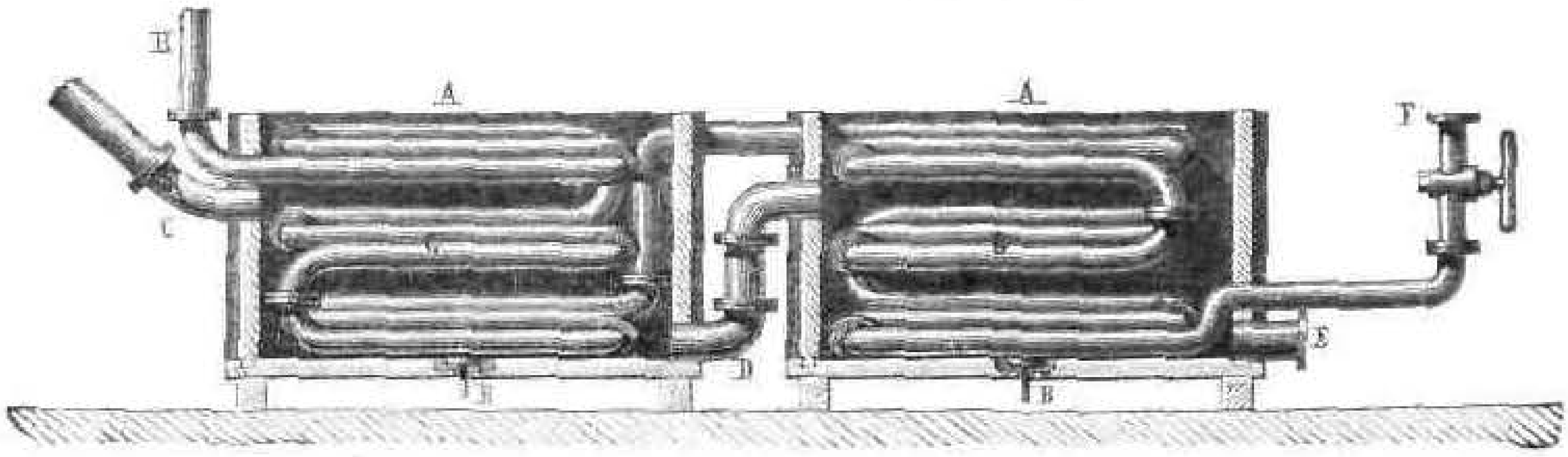


Fig. 68.

tines in three rows, and which are traversed successively by the pure water; H discharge pipe for the clean hot water. The complete apparatus contains 120 square metres of heating surface. The effects produced have been proved by several series of experiments made by different manufacturers. According to one of these, the mean temperature of the water in the baths was 58°, that of the water heated 53°. In a day's work of eleven hours the apparatus received the waters of 70 tanks, each containing from 0·750 cubic metres to 0·800 cubic metres, that is to say, from 56·00 cubic metres to 42·50 cubic metres, and the volume of hot water supplied was 43·200 cubic metres. In another trial the mean temperature of the dirty water was 56°, that of the heated water 48°. The volume of dirty water discharged per day was 40 cubic metres, and that of the cold water 37 cubic metres. In another experiment, which lasted an hour, the apparatus received 3·10 cubic metres of dirty water at 66°, and discharged 3·33 cubic metres of clean water at 50°; they therefore gained about 0·8 of heat.

OBSERVATIONS ON THE DIFFERENT APPARATUS DESCRIBED.

2078. Nickol's apparatus, the oldest of all which I have only just noticed, would certainly be the best for producing exchange of temperature if its dimensions were suitable and if its outer surface was covered with non-conducting material, but it has too great a length and above all the difficulty of cleaning places it for industrial purposes below the others, at least when the hot water forms deposits.

2079. Messrs. Schiers and Sons' apparatus has the advantage of taking up little room; the cooling surfaces are well utilised, as the 80 square metres of transmitting surfaces suffice for cooling 6 cubic metres of malt per hour from 100° to 22°, but it has the great drawback of being difficult to clean.

2080. The arrangements shewn in figures 63, 64, 65, and 66, have the drawback of placing the current of water to be heated between two currents which work in contrary directions, but which are necessarily at different temperatures, and consequently the effect produced is less than if each elementary current of hot water was surrounded with special currents of cold water. In figure 67 each current of cold water follows an opposing current of hot water, but the currents, separated by a simple metal partition and moving in opposite directions do not heat as much as if they were rectilinear. In figures 65 and 66 it would evidently be necessary to have the spirals separated by a thin plate of non-conducting material which would divide the intermediate into two equal parts. In the case of figure 67 the metallic partitions should be formed of thick non-conducting plates.

2081. Mr. Pimont's apparatus takes up a great deal of room, and the transmitting surfaces are not well utilised, because the movements in opposite directions do not take place in an effective manner, and the sections of the two circuits are too large. The following are the results from the numbers which we have given:—In Messrs. Schiers and Son's apparatus, with 80 square metres of transmitting surface, they cooled in one hour 6 cubic metres of malt from 100° to 22°, consequently heated 5

cubic metres of water to 65°, whilst in Mr. Pimont's apparatus the effect of the 120 square metres of transmitting surface would be to heat to nearly 48° about 4 cubic metres of cold water per hour, the hot dirty water being at 56°. It is important to note that if the cold water entered at 15°, the simple fact of the equal apportionment of the heat between the two equal masses supposed to have the same caloric capacity, the common temperature should be 35°. As a matter of fact, in a series of experiments made at Mulhouse, the hot dirty waters being at a temperature of 67·54° the same quantity of clean water was in $2\frac{1}{2}$ hours heated to 65·50°, but the volume of water was only 1·600 cubic metres, and consequently 0·64 cubic metres per hour, and it is natural that the exchange of the temperatures could be better realised as the movements are slower.

2082. Mr. Pimont, although his apparatus is much inferior to those which produce a similar effect in the manufacture of beer and other industries, has however, rendered a real service to the proprietors of dye works in calling their attention to the enormous loss of heat resulting by not using the hot water from the worked out baths, and by offering them an apparatus to make use of this heat.

2083. The arrangement which appears to us to be the best to effect the exchange of temperature between two

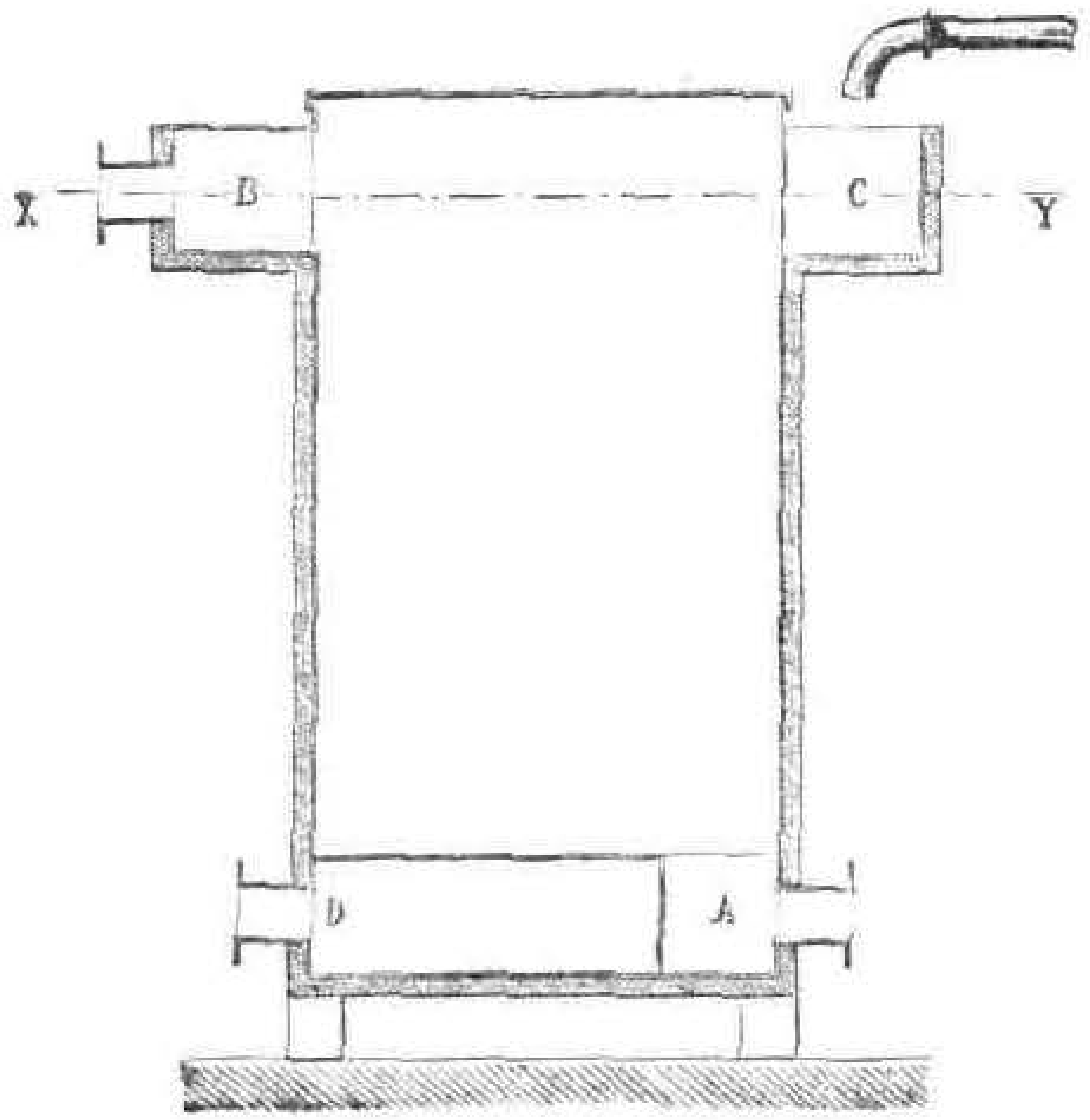


Fig. 69.

liquids is shewn in vertical and horizontal section in figures 69 and 70, the latter being a section on the line X Y of the former. The apparatus consists of a series of very narrow vertical vessels about 1 centimetre wide, open above and closed below, and separated one from the other by spaces of equal width, these vessels all communicate at the bottom with a small vessel A into which the fresh water falls, and laterally a little below the upper part, with a vessel B through which the heated liquid runs out, the spaces communicate at the upper part with the lateral vessel C where the hot water enters, and runs out out at the bottom part by the pipe D. It will be seen by this arrangement that by regulating the flow of the fresh and dirty water, which flow in opposite directions in very narrow channels, a nearly complete exchange of temperature can be obtained, and the channels can easily be cleaned, all being open at the top. In order to prevent loss of heat by evaporation at the top, the apparatus can be closed with a wooden lid covered with a polished metal plate. The two liquids will tend to move regularly by isothermal trenches, the dirty water because it cools in descending, the fresh water because it rises while heating.

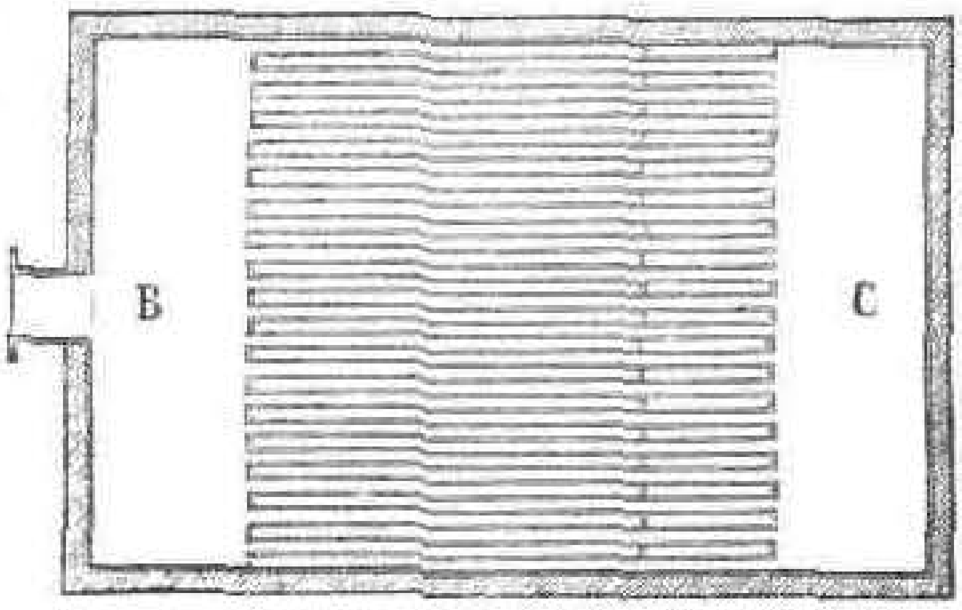
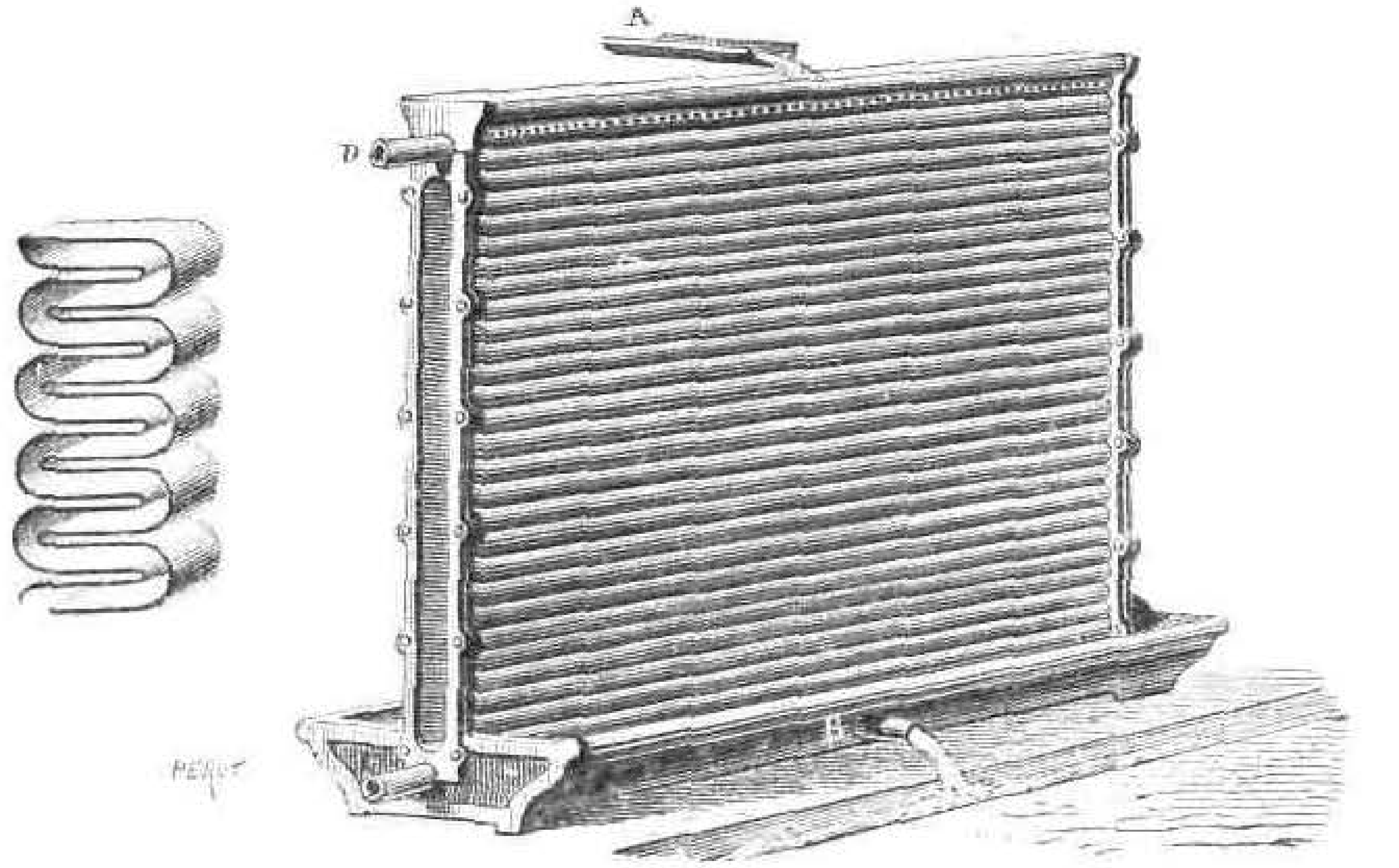


Fig. 70.

This arrangement has only one drawback, that you cannot maintain a regular pressure on the fresh water which is heating, on account of the necessity of keeping the channel for the two currents open so that they may be cleaned, it would always be possible to get over this difficulty by hermetically closing the lid by a joint, which could easily be made or broken.

2084. Messrs. Laurence and Co.'s capillary refrigerators are now much used in England, and they are beginning to use them in France for cooling beer malt, distiller's wash, or the thick distillery malts. The apparatus is formed essentially of two copper plates bent in such a way as to form a very narrow twisted channel and placed vertically. Figure 71 represents a section of a portion of this channel; the complete apparatus is shown in figure 72. A is the supply for the malt which is distributed by



Figs. 71 and 72.

a gutter and by holes on each side of each of the undulating sides of the apparatus, along which it falls in a very thin layer into another gutter at the bottom, out of which it flows through the pipe B. The cold water penetrates the interior of the apparatus by the pipe C and leaves by the pipe D. By giving sufficient development to this apparatus it would be possible to get a very rapid cooling and bring the malt to a temperature not exceeding half a degree of that of the water. If malts of low fermentation are required they may be cooled to 3° or 4° by dividing the apparatus into two parts by a horizontal section, or better still, by making two undulated parts one above the other on the same vertical plane; the cold water circulates in the upper part, in the lower part the iced water. The name of capillary refrigerator is given to this apparatus, because the malt maintains itself by capillarity in the crooked part formed by two successive undulations; it is however necessary to remark that the malt does not actually remain in these spaces, it is continually being driven out by that which descends in a thin layer.

When it is wished to preserve the malt from the influence of atmospheric air there can be fitted on each side of the apparatus a trap door working on a hinge, to the height of the holes for distributing the malt, which can be opened whenever necessary, so as to diminish more or less the influence of the outside air.

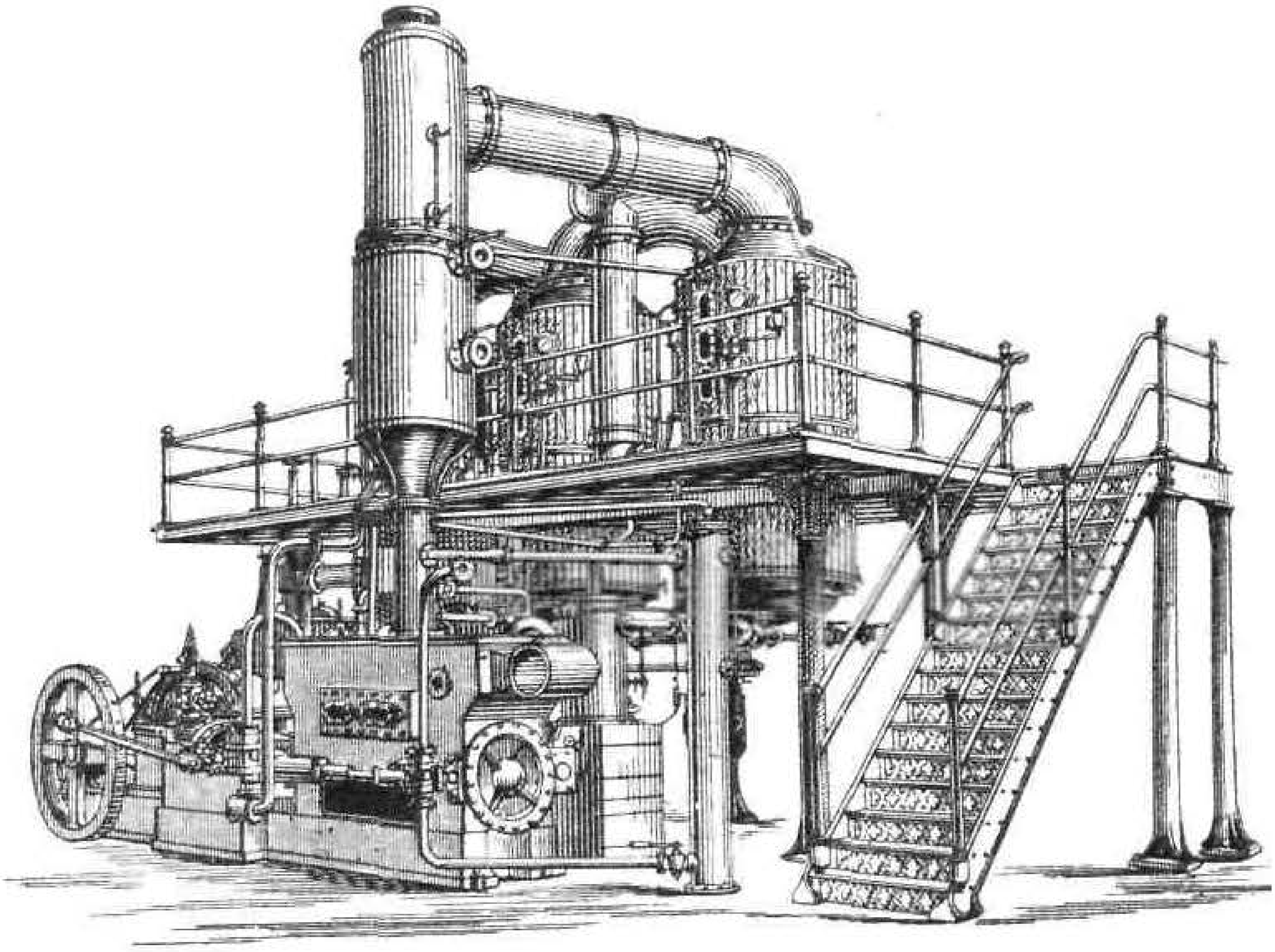
The most remarkable part of these apparatus is the ease with which they can be cleaned, to remove the deposits left by the malt it is only necessary to break the outside surface.

A refrigerator 1·80 metres long, and 1·20 metres high, is sufficient to cool from 75° to one degree below the temperature of the cold water used, 33 hectolitres of malt per hour.

Applied to thick malts, such as those in distilling from grain, the apparatus only differ from those used for beer malts, by the curves being a little larger so as to facilitate the cleaning.

2085. Liquids can also be heated by immersing the vessels containing them in other vessels containing liquids heated directly. This method (called in French "Bain-Marie") has nothing special to be noticed here.

FOSTER AND CAMPBELL'S



TRIPLE EFFET.

EXTRACTS

FROM

FRANCISCO SACH'S

UNIVERSAL REVIEW OF THE PROGRESS

OF

SUGAR MAKING,

1883, 1884, 1886, 1887.

CHAPTER IV.

EVAPORATION AND BOILING TO GRAIN, 1883, 1884.

A.—General Observations on Evaporation—

The evaporation of juice generally takes place in Double or Triple Effet apparatus constructed either vertically or horizontally.

The *vertical type or Robert apparatus* are divided into three parts. The lower compartment, the tubes, and *a portion of the upper compartment are filled with the* juice, whilst the steam or vapour circulates among the tubes.

In the horizontal type, on the contrary, the steam or vapour circulates in the tubes and the juice surrounds them. In Walkshoff's arrangement the tubes are superseded by serpentines.

The question of evaporating the juices in an economical manner is certainly one of the most important in the *manufacture of sugar,* and we need not be surprised that numerous efforts have been made in this direction, chiefly in Austria, where the fiscal regulations compel the manufacturers to produce highly diluted juices, of which the quantity sometimes reaches 200 % of the weight of the beetroot worked.

Amongst these innovations we will quote particularly the apparatus of Jelinek and of Weibel-Piccard in Austria, of Rillieux in France, Simirenko in Russia, &c.

Before passing on to the details of the apparatus we think it better to give a short summary of the theory of evaporation, taking as the basis of our arguments the developments given by Hugo Jelínek* (Prague). This will perhaps permit many of our readers to appreciate more easily which of the different systems proposed merits our confidence.

We will first take the case of a horizontal or vertical Single Effet apparatus, which is the most simple, indicated as follows :—

- t° — The temperature of the juice on entering the apparatus usually at 75° C.
- t_1 — The temperature of the boiling juice in the last vessel at 60° C (supposing that a maximum vacuum of 0·608 C can be formed.)
- t_2 — The temperature of the steam or vapour heating the juice to be 112° C (when the exhaust steam used for heating the apparatus has a pressure of $1\frac{1}{2}$ atmospheres).
- C — The co-efficient of transmission in proportion to one square metre of heating surface per minute and per 1° C of difference of temperature $(t_2 - t_1)$. This co-efficient is equal to 22 for the Wellner-Jelinek apparatus.
- S — The heating surface of the evaporating apparatus.
- $Q = S\,C\,(t_2 - t_1)$—The number of calories transmitted by the surface S.
- P — *The weight of the heating vapour condensed* in the tubes expressed in kilos per minute.
- P_1— The weight of the water evaporated by the heating surface in kilos per minute, will give

$$Q = P \quad (606{\cdot}5 - 0{\cdot}708\ t_2)$$

and $$Q = P_1 \quad (606{\cdot}5 + 0{\cdot}305\ t_1 - t_0)$$

which gives $$P = \frac{Q}{606{\cdot}5 - 0{\cdot}708\ t_2}$$

and $$P_1 = \frac{Q}{606{\cdot}5 + 0{\cdot}305\ t_1 - t_0}$$

* See pamphlet : Evaporating apparatus and their installation, by Hugo Jelinek, 1st part.

N.B.—We have not held strictly to the letters adopted by Mr. Jelinek in his formula.

This formula applied to a Single Effet, the number of calories transmitted per square metre of heating surface will be—

$$Q = 1 \times 22 \times (112 - 60) = 1{,}144 \text{ calories,}$$

$$\text{also } P = \frac{1{,}144}{606{\cdot}5 - 0{\cdot}708 \times 112} = 2{\cdot}163 \text{ kilos of steam,}$$

$$\text{and } P^1 = \frac{1{,}144}{606{\cdot}5 + 0{\cdot}305 \times 60 - 75} = 2{\cdot}08 \text{ kilos of water.}$$

2·163 kilos of exhaust steam can thus evaporate 2·08 kilos of water, or 1 kilo of steam 0·96 kilo water.

The quantity of water evaporated per hour is—

$$2{\cdot}08 \times 60 = 124{\cdot}8 \text{ kilos.}$$

If the same calculation is made for a Double Effet, supposing that the vapour which should heat the second vessel has a mean temperature of $\frac{112+60}{2} = 86°$ C., it will give :—

(*a*) For the first vessel	P=1·083	kilos of	vapour condensed.
	P=1·025	,, ,,	water evaporated.
(*b*) For the second vessel	P=1·025	,, ,,	vapour condensed.
	P=1·038	,, ,,	water evaporated.

Also 1 kilo of exhaust steam can evaporate :—

In a Triple Effet	2·85	kilos of water.
,, Quadruple Effet	3·79	,, ,,
,, Quintuple Effet	4·72	,, ,,

These calculations are not all strictly correct.

The boiling point of the juice has been taken as that of water, whereas it is in reality as follows :—

Water	100° C.
Juice at 30 % Balling	101° C.
,, 50 % ,,	102° C.
,, 60 % ,,	103° C.
,, 70 % ,,	106° C.
,, 79 % ,,	112° C.
,, 90 % ,,	130° C.

However when it is simply a question of comparing the different systems of evaporation these differences are not of great importance.

Jelinek draws from these an important conclusion which agrees with a similar argument already made by Horsin-

Déon,* viz. :—that *the heating surfaces of the several vessels of the same evaporating apparatus should be equal* when it is wished to produce the same effect in all the vessels, so that the principle admitted so far of making the second vessel larger than the first and the third larger than the second is wrong. Another reason frequently put forward that the first vessel should be made smaller than the last, on account of the incrustations of the tubes, is inadmissible; and it would be better to frequently clean the apparatus or to have a reserve vessel.

Having thus disposed of the question of principle, let us see what means are at our disposal to increase the power of evaporating apparatus and to economise the fuel.

First, the temperature of the heating steam could be increased by adding to the exhaust steam direct steam from the boilers. This would not only increase the *differences of temperature*, on which depends the quantity to be evaporated, but would increase the velocity of the passage of the vapour and produce a more rapid evaporation. This is one of the principles on which Rillieux's system is based. Another advantage of this system is the *logical separation of the condensed waters coming from the* intermediate vapours, called ammoniacal waters, and the discharge by a special pipe of the gaseous products (ammoniacal ?) which are detrimental to the evaporation. Others have proposed reducing the temperature of the condensing vapours of the last vessel (this would also increase the power of the evaporating apparatus) by interposing a calorisator for the waters or the juices between the last vessel and the condenser, by increasing the power of the pump or the action of the condenser, or by taking away from the condenser the gaseous products which prevent a higher vacuum being formed.

Louis Walkhoff (Kieff) also proposes a system of this kind, but he has not considered it necessary to publish the details.

We will speak later on of the Weibel-Piccard system, the principle of which is to utilise the vapours from the juice, not in another vessel, but in the same vessel, by submitting them to a pressure which causes their temperature to increase.

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* We refer those who would specially study this question to the very detailed work published by Horsin-Deon in his Treatise on the Manufacture of Sugar, part of which will be found in this work at page 27.

The velocity of the juice in the vessel can also have a great influence on the rapidity of the evaporation, as the following experiments made by Jelinek shew :—

Velocity of the juice per second, expressed in metres.		Calories transmitted per square metre.
	0·312—22·7	
	0·640—33·6	
	1·020—46·9	
	1·640—69·9	

It is also an important point to be considered whether the heating vapour during the time it should act, should be always at the same pressure, and while one portion of the vapour is condensed it would be necessary to diminish gradually the area of the tubes, or of the pipe through which the vapour is supplied.

Jelinek also insists on the free discharge of the condensed water, and consequently he requires that the velocity of the vapour should be much higher than in ordinary apparatus. As an example, a factory working 200,000 kilos of beetroot per 24 hours utilises 120 horse power, requiring about 30 kilos of steam per hour per horse power. The exhaust steam which could be admitted equal to that of the direct steam, represents an absolute pressure 1·5 atmospheres, or a volume of 12 cubic metres per second. The inlet of this exhaust steam into the heating chamber of the evaporating apparatus being effected by means of a valve of 0·25 metre diameter, it enters at a velocity of 23 metres per second, so that if the evaporating apparatus is horizontal and contains 400 tubes of 0·055 metre diameter each, the steam will pass through the tubes at an initial velocity of 0·052 metre only, that is to say, that the steam will be nearly motionless, and the condensed water will be only incompletely discharged.

Some time since Louis Walkhoff, Kieff, constructed in Russia an apparatus which overcame this difficulty. Jelinek gives a description of one of these.

This same valve of 0·25 metres diameter is connected by a pipe to a rectangular vessel of the same area (0·049 square metres), also 19 copper serpentines of 0·08 metres diameter and 19 metres long lead from this vessel, having a total area equal to 0·095 square metre. The steam or vapour entering with a velocity of 23 metres per second passes through the pipes with an initial velocity of

$$23 \times \frac{49}{95} = 11{\cdot}8 \text{ metres per second.}$$

Walkhoff completes the description of this apparatus by showing that the diameter of these serpentines decreased from 90 to 15 millimetres as the vapour condensed, and that they terminated in a tube bent back and fitted at the bottom with a cock for drawing off the condensed water. This arrangement generally applies only to the first vessel of the apparatus.

A very interesting Double Effet apparatus was constructed as early as 1875 by Simirenko at Sidorovka, Russia. The first vessel was fitted with serpentines, and the second with horizontal brass tubes 0·057 metre diameter and 3·700 metres long. In order to reduce the free area of the tubes as the volume of the vapour (or rather its expansion) decreased, they fitted in them wooden cones which contracted the area so as only to leave a space of 2 millimetres at the end between the cone and the tube.

The apparatus was not a horizontal cylinder, but a cube surmounted by a dome. It had 4 heating chambers, one on each face, so that the rows of tubes crossed each other perpendicularly. The condensed water flowed out at the end of each row of tubes.

A similar arrangement was recommended by Simirenko for vertical apparatus. He also made experiments to determine whether the cones have really any effect on the rapidity of the evaporation. For this purpose he made several tubes project beyond the heating chamber, so that he could collect the condensed water from them, he operated at various temperatures, and placed the cones only in a few of the tubes.

The following are the quantities of water collected in these experiments :—

Temperature	90·4°C	88·3°C	87·7°C
Tubes without cones	4·500 kilos.	4·120 kilos.	3·300 kilos.
,, with cones -	5·400 ,,	5·205 ,,	4·350 ,,
Differences -	20%	26%	31%

He also compared iron and brass tubes and found that the latter evaporated from 22 to 49% more than the former.

He also wished to see if the lower tubes evaporated less than the upper ones, for the reason that in the former the juice which surrounds the tubes has less action by the pressure of the column of liquid above it.

The following are the quantities of condensed water collected in each row of tubes —

1st row (top)	1·843 to 2·025	kilogrammes.
2nd ,,	1·727 ,, 1·360	,,
3rd ,,	1·611 ,, 1·350	,,
4th ,,	1·431 ,, 1·277	,,
5th ,,	1·235 ,, 1·255	,,
6th ,, (lowest)	622 ,, 977	,,

The experiment was made at a temperature of 100 to 102·4° centigrades.

In consequence of these experiments, Simirenko altered his evaporating apparatus so that steam entered the lower row of tubes and discharged by the upper tubes. The utility of this arrangement appears to us doubtful.

We will now describe another apparatus of Simirenko's (fig. 73).

This is a vertical cylinder for collecting the heating vapours condensed in the different vessels of a Single Effet apparatus by the tubes W W_1 W_2. This cylinder is nearly filled with water, so as to prevent the ammoniacal water drawing in the steam, the pump drawing off the superfluous water by means of the pipe A at the upper part of the cylinder, at the lower part of the cylinder there is a second pipe which can also communicate with the pump when it is necessary to completely empty the cylinder. When the corresponding cock is closed the time necessary for filling the cylinder with condensed water up to the level of the upper pipe can easily be observed, a gauge being fixed there for that purpose. By means of this arrangement a good deal of useful information on the working of the evaporating apparatus can be obtained.

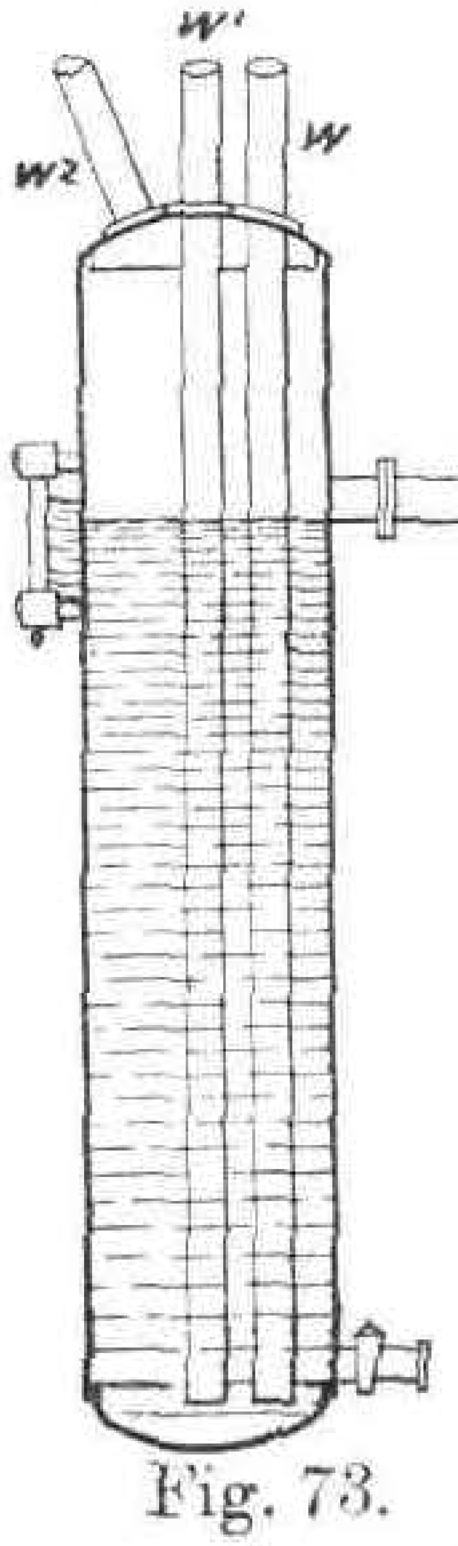

Fig. 73.

Last year H. Jelinek* (1882) continued his very interesting articles on evaporation and boiling to grain. Considering the great importance of this subject we think it may be of use to give a summary of them.

* B Z, vii, p. 53, 251, 291, and 449, and viii, p. 122.

He first shows how important it is that there should exist in the reservoirs which receive the condensed waters from the vessels a pressure not much less than that of the vapour on entering these vessels.

As an example the temperature of the heating vapour in the first vessel is say 106°, and that of the boiling juice 94°, the difference of temperature will be 12°. If the vapour is completely condensed so that only condensed water leaves the vessel it will have a temperature of 94°, and the mean temperature of the heating vapour will be $\frac{106+94}{2}=100°$. The mean difference of temperature will then only be 6°, or 50% less than found above.

If on the contrary, the entry of the vapour is forced so that a portion of the uncondensed vapour is discharged with the condensed water at 100°, the difference of temperature will be $\frac{106+100}{2}-94=9°$ or only 25% less than in the first case, but in this case there will be a much larger consumption of vapour. The working of the Triple Effet can be further increased by making use of a closed water receiver in which there is always a certain pressure nearly equal to that of the vapour on entering, the water passes out by a valve regulated accordingly.

Jelinek then passes on to a description of several accessories (see pages 159 and following of this Book).

Jelinek has also demonstrated the necessity of fixing in the first vessel a valve which will supply the direct steam at 3 atmospheres either into a serpentine fitted in the first vessel in the old apparatus, or in a special system of tubes in the Wellner-Jelinek system. At any rate the other extremity of this heating arrangement should not *communicate with the exhaust steam, if it does the* mean pressure in this system of heating will not be three atmospheres but $\frac{3+0{\cdot}5}{2}=1{\cdot}75$ atmospheres.

[It should be noted that all this is written for Austria where the juices are usually strongly diluted, in other countries it is rarely necessary to supply direct steam to the Triple Effet.—F. S.]

Jelinek condemns this method of increasing the pressure of the exhaust steam on account of the inevitable losses which follow it, and only admits it in case it is wished to utilise the heat of the condensed water for boiling to grain or some other heating purpose.

The nature of the gases disengaged from the juices has not yet been sufficiently considered ; we only know that it is chiefly air, ammonia, carbonic acid, &c., mixed with steam. We have been led to believe that these gases, according to the laws of diffusion, mixed themselves instantaneously ; it seems, however, that this is not the case. A similar phenomenon has been noticed in Russia, where wood is generally used for fuel, the products of combustion being used for the carbonatation. It was then observed that the gases taken at the bottom of the flue contained 10 to 11% of carbonic acid, whereas that taken at the upper part contained 4 to 5%, the gas collected immediately behind the fire bridge had even 12 to 13% of carbonic acid, whilst that passing immediately under the boiler had only 7%. This also takes place in evaporating apparatus. It has been noticed that the separation of the gases takes place for the most part in places where they move slowly, and particularly in apparatus with vertical tubes. It is, however, indispensable to have an arrangement for discharging the gases out of the apparatus. There is also an air valve in the first vessel of the horizontal apparatus, and in those of the Wellner-Jelinek system, but it is only used when commencing work. In the second and third vessels, on the contrary, air valves are necessary.

Jelinek explains this separation by saying that the molecules of gas at the moment of their formation are isolated, and being infinitely small, separate by the laws of gravity, the diffusion can however only take place at the end of a certain time. On the other hand when the mass is agitated there is always a more or less uniform mixture going on. It is necessary to make this mixture, consisting of vapour, condensed water, ammonia, &c. pass as rapidly as possible through the whole apparatus, either into the exhaust steam reservoir or into the receivers for collecting the water condensed from the other vessels.

These receivers are made of cast iron and of any form. The condensed water with all the gases enter at the upper part by a valve A, and the condensed water flows off lower down by another valve F towards the ammoniacal water pumps. This valve opens intermittently by means of a float E, which does not allow the vessel to entirely empty itself.

When the pressure of the gas in this vessel becomes too great, another valve at the upper part H opens, and through it the gas escapes towards the heating chamber of

the next vessel, so the uncondensed vapour contained in the mixture can again be utilised.

Jelinek separates the chamber into two parts by a vertical partition D which does not go quite to the bottom. The portion of the chamber B communicates with the upper part of the heating chamber by the valve J so that a uniform pressure is established throughout the whole system.

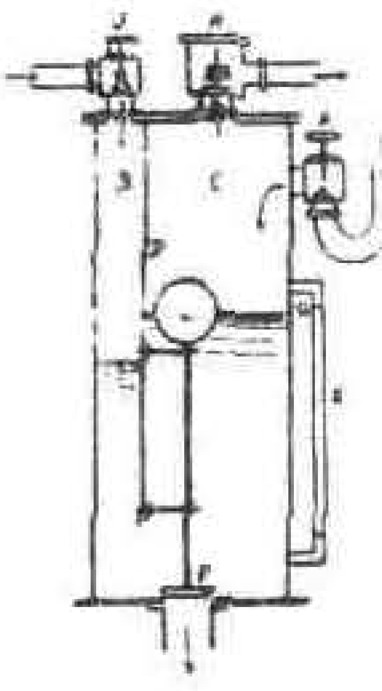

Fig. 74.

G. The ammoniacal water pumps. It is better to have one of these for each vessel, and to fix the depression valves on the pumps. It is easy to calculate their dimensions.

H. The communication pipes for the steam between the different vessels.

If we indicate :—

Q = The section of one of these pipes.

S = The heating surface of the vessel in square metres.

V = The velocity of the vapours per second in metres.

P = The weight of the vapour produced in one vessel per minute and per square metre.

M = The weight of a cubic metre of vapour corresponding to the pressure in the vessel, we will have the practical formula :—

$$Q = \frac{S + P}{60 \times V \times M}$$

The maximum velocity given to the vapours is 60 metres per second ; it is however as well to limit it to 20 or 30 metres and not to exceed 40 to 50 metres, except in the last vessel of an apparatus with very large surface, so as not to make the vapour pipes too large in diameter. It will be noticed that according to this principle the connecting pipes should increase in size from the first to the last vessel.

I. The condensation is generally made by injecting water into the vapours coming from the last vessel.

There are two different systems :—

(*a*) The condensation takes place in a special condenser, so that the water is discharged by a simple

barometric pipe or by a water pump, whilst the air is drawn off by a special air pump called the dry air pump.

(*b*) The water and the gas are drawn off together by the wet air pump.

In the first case the installation is more costly, as very long tubes are necessary, as well as a special condenser. Further, there is an important increase of motive power, as it is necessary to raise the water to a height of 10 metres. Per contra, the engine and pumps have more work to do than in the second case, and further, there is the danger of incrustation in the pump when pure water cannot be obtained.

[We pass over the calculations made by Jelinek to determine the consumption of fuel in this case, as he has not taken into account the re-employment of the exhaust steam in the evaporating apparatus, and consequently his calculations are not quite exact.—F. S.]

Jelinek admits that the water necessary to condense the vapours proceeding from the last vessel is from 20 to 30 times its weight, according to the temperature of the water used. Nevertheless, the quantity of condensing water required may be much larger when the condenser is badly constructed, that is to say, that the water injected does not get into sufficiently close contact with the vapours.

The injection of water is generally done by means of a rose of perforated pipe or a sieve which easily choke when the water is calcareous.

On the other hand the surface for condensing is too small, there are also other bad arrangements.

The majority of condensers are too small. their volume should be 1½ to twice the volume of the air pump.

Jelinek recommends using a special condenser

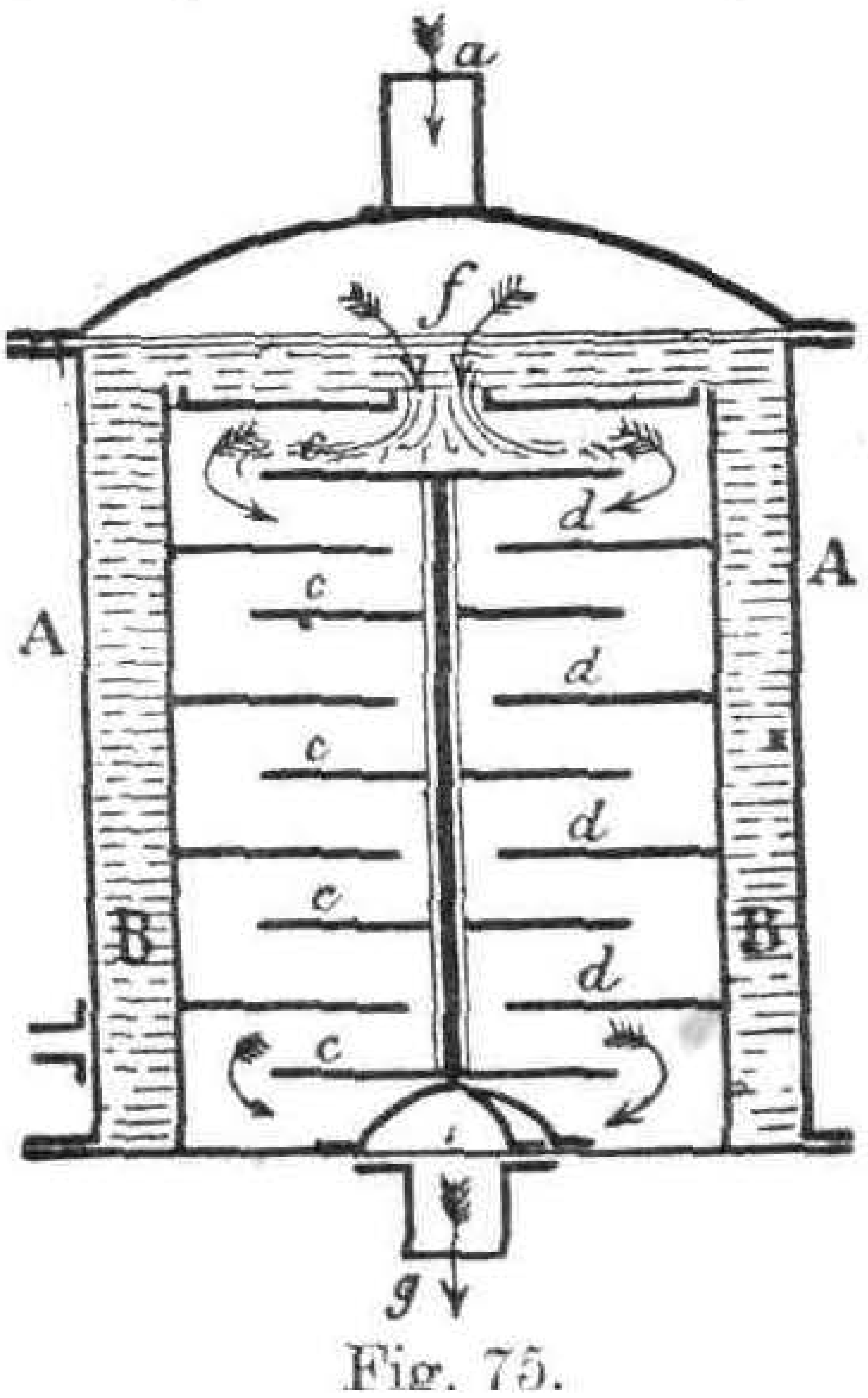

Fig. 75.

of which we give a diagram (fig. 75) a description of which will be found on page 180.

The mixture of vapour and condensing water enters by the opening *f* into the inner cylinder, and leaves it by the lower opening *g* after the vapour has been completely condensed. The water passes either direct to the air pump or into a separator for the dry air pumps. This system has the advantage of never choking.

Instead of injecting the water direct into the condenser, surface condensing was formerly used; the vapours passed through serpentines fixed vertically and cooled by the condensing water. This system invented by Desrenne has been abandoned. Per contra, the vapours of the last vessel are at present frequently used for heating the juices or the water of the diffusers by means of a calorisator, *which at the same time increases the effect of the condensation.*

K.—THE CALORISATORS AND THE HEATERS OF FEED WATER.

It is highly advantageous to utilise the heat lost by the vapours of the last vessel for heating the diffusion juices. But the calorisators or heaters used for this purpose have often given poor results, because the velocity of the juice was too slow, also the heating.

Jelinek recommends using a heater similar to his evaporating apparatus, from which the upper part has to be removed and replaced by a simple cover. The juice goes through the tubes and the vapours surround them.

The velocity of the juice then becomes much greater, and the apparatus will go well.

L.—THE WET AIR PUMP

is for the purpose of removing :—

1st. The condensing water, the quantity of which is between 20 and 40 times that of the water condensed.

2nd. The condensed water.

3rd. The air contained in the condensing water, the volume of which is, according to Bimsen, at the atmospheric pressure (0·76 metres).

For	0°	Centigrade	- 0·02471
,,	5°	,,	- 0·02179
,,	10°	,,	- 0·01953
,,	15°	,,	- 0·01795
,,	20°	,,	- 0·01704

4th. The gases formed by boiling the juice.

5th. The air which enters through the pores of the apparatus.

The volumes of gas indicated by 4th and 5th are entirely unknown to us, but they should be very considerable.

Practice proves that such dimensions can be given to the air pump, that the piston can travel through a volume of 0·3 cubic metres for each kilogram of vapour to be condensed per minute, for condensing steam engines a volume of 0·12 to 0·15 cubic metres is usually given.

It is necessary to give the same dimensions to the dry air pump, viz. 0·3 cubic metres for each kilogram of vapour to be condensed per minute.

After these details Jelinek passes on to the general question :—

What is the production and utility of the vapour in regard to evaporation, and what economy is it possible to make in the two systems of evaporation?

Let us first quote an article from the journal of the Austrian manufacturers* in which Polaczeh (manager of sugar works in Russia) shews the advantage of using high pressure expansion engines in sugar works.

Jelinek confirms this opinion by quoting as an example a sugar factory which works 10,000 kilos of beetroot per hour with a motive power of 150 H.P.

It is admitted that ordinary engines consume 45 kilos of vapour per horse power per hour, and that we must allow 0·30 for loss in condensing. The total loss in vapour will thus be per day $150 \times 45 \times 0{\cdot}3 \times 24 = 48{,}600$ kilos.

With an expansion engine the consumption of vapour will only be 15 kilos per horse power per hour, and the loss equal to 0·25. The total loss of vapour will thus be $150 \times 15 \times 0{\cdot}25 \times 24 = 13{,}500$ kilos, or 35,100 kilos less, equal to 5,850 kilos of coal.

We see by this that the losses depend chiefly on the quantity of vapour consumed, and further that it is dangerous to considerably increase the pressure of the exhaust steam, as is often done. Lastly, it would be

* B.Z., vii., p. 449.

advantageous on account of the consumption of fuel to replace all the small engines in sugar works by one large central engine, well constructed.

Unfortunately local circumstances rarely permit of this.

The natural consequence of using economical engines is the necessity of supplying direct steam into the first vessel of the evaporating apparatus.

Care should also be taken to avoid the expansion of the direct steam in the steam chamber; otherwise a considerable loss of heat may take place.

We have said that it is dangerous to increase the pressure of the exhaust steam. There is also another reason for this. It may be believed that the vapours develop more heat when at a high pressure, but that is an error, because in this case the condensed water also becomes hotter, its temperature being equal to that of the vapour from which it proceeds. It is rather the contrary which takes place, as can be seen by the table on page 188.

[We will however add, that heating steam of a high pressure may be advantageous in a factory which has too small an apparatus for evaporating, and could by this expedient do more work, from which will result indirectly a reduction in the losses of vapour. On the other hand, the boiling will perhaps be more lively in the vessels in consequence of the greater difference of temperature.—F.S.]

Jelinek also observes that it has often been wished to divide the steam boilers into two groups, one at low pressure for heating the liquid to be evaporated, and the other high pressure for the engines, but this arrangement can only be of material service if the construction of the steam engine be altered accordingly.

It is certainly an advantage to carry the evaporation as far as possible, say to 60 % Balling. But as it is impossible to filter juices so highly concentrated, the heating surface of the last vessel must be divided into two parts, one of which is used to evaporate the juices to 50 % Balling and the other to finish the evaporation of the filtered juices to 60% Balling.

Apparatus for boiling to masse cuite by the Double Effet could be heated by the vapour of the first vessel of the

evaporating apparatus, or those of the Triple Effet by the vapour of the last vessel, but the advantage of this process, to say the least of it, is very doubtful. The vapour from the last vessel of the evaporating apparatus could also, as we have said, be used for heating either the water for the diffusion of the juice before carbonatation, and it is certainly an excellent idea, provided always that the expense of fitting up this arrangement does not counterbalance the saving of fuel.

The slight difference of temperature will require sufficiently large heating surfaces.*

The vapour from the first vessel may also be used for similar purposes, but this appears less advantageous. Finally there is an advantage in using the water from the condensers for the diffusion. By mixing them with cold water a temperature of 20° C can easily be obtained.

HORSIN-DÉON † contests Jelinek's conclusion on certain points. He does not admit that the losses of vapour by condensation in the engines are proportional to the quantity of vapour discharged, and consequently to the back pressure on the piston, and he puts forth this precept that the condensations are not proportional to the quantity of vapour discharged, but to the condensing surfaces and to the difference of temperature between this surface and the surrounding air which is a mere nothing, and only varies a few degrees, working with or without back pressure. The losses by condensation do not sensibly increase if the engines work with back pressure, especially if the exhaust pipes are covered with a non-conducting composition. According to Horsin-Déon the pressure of the exhaust steam can be increased to heat the Triple Effet. The losses from the condensation and from the steam are not 0·3 of the total weight of the vapour used, but much less, perhaps only 0·003; it can be proved, that an iron pipe will only condense 1·4 kilos of vapour per square metre of surface per hour.

Jelinek‡ replies to this by quoting Professor Schmidt's formula—

$$y = \frac{0{\cdot}60}{v\sqrt{p_1 \quad \frac{s_1}{s}}}$$

* Note what was said about calorisators and heaters.
† J.a. F.S. 24, No. 47 and 50. ‡ B. Z., viii. p. 124.

in which y=The loss of vapour by cooling.

v=The velocity of the piston per second.

p=The pressure of the direct steam.

$\frac{s^1}{s}$=The degree of admission of the steam into the cylinder.

If we take $v=1$ metre, $p_1=3$ atmospheres, and $\frac{s_1}{s}=0{\cdot}8$ we will find $y=\frac{0{\cdot}60}{1\sqrt{3\times 0{\cdot}8}}=0{\cdot}38$, or even more than 0·30.

HORSIN-DÉON also reproaches Jelinek with having denied the advantages of the Multiple Effet and with ignoring the merits of Rillieux. These reproaches do not appear to us to be well founded. On the contrary, Jelinek is a convinced admirer of the Multiple Effet and has also recognised the merits of Rillieux's works on evaporation.*

In an article on economising fuel in the manufacture of sugar, Paul Horsin-Déon establishes the following points :—

The consumption of vapour varies considerably in *sugar factories, and that from various causes*—

1st. *The percentage of juice extracted from the beet*-root. It is not necessary to compare the percentage of coal required for the weight of beetroot in kilos but per hectolitre of juice.

2nd. If evaporated by Double or Triple Effet.

3rd. If the vapour pipes are or are not covered with a non-conducting composition.

4th. The type of the steam boilers and the arrangement of the flues.

For working 1,000 kilos of beetroot giving 12 hectolitres *of juice, 800 kilos of steam or vapour would be* required, and under favourable conditions 100 kilos of coal, equal to $8\frac{1}{3}$ kilos per hectolitre of juice.

One of the most important reasons for consuming so much coal is the low degree of concentration of the juices when leaving the evaporating apparatus, justified either by the insufficiency of the apparatus, or by the prejudice that we cannot boil to grain with highly concentrated juices.

* J. de F. S., 21 No. 1, and Jelinek Evaporating apparatus, p. 37.

Calculation shows that by concentrating the juices in the Triple Effet to 15° B instead of 27, as is often the case, there is an increase of 24 kilos of coal burnt per 1,000 kilos of beetroot. The loss is really much more, as by concentrating to 15° B only, there is an excess of exhaust steam which must be pure loss, so that it would be easy to consume 150 kilos instead of 100 kilos per ton of beetroot.

A good working Triple Effet ought to evaporate 10 hectolitres of juice per square metre of heating surface in 24 hours to 27° Beaumé.

Different means have been proposed for using the heat lost by the gases in the chimneys, but none have answered the purpose. One of the last was to replace the steam boilers, which only generate on an average 6 kilos of steam per kilo of coal, by tubular boilers which give 8 kilos of steam, or a difference of 33 % in the consumption of coal.

HORSIN-DÉON strongly recommends heating the Multiple Effets in the following manner; give pressure in the first vessel of the Triple Effet and slightly more than the atmospheric pressure in the second vessel (the engines will stand it). The vapour of the first vessel will be 115° and that of the second 100°.

For the diffusion the calorisators may be heated by the vapour from the first vessel, also the first carbonatation, at the second carbonatation the vapour of the second vessel can be used, &c. Calculation shews a saving of at *least 30 % of fuel by working in this manner.* Practice has proved a saving of 50 % at Wehetul, and 60 % at Ouval with perfect evaporating apparatus; at Wehetul they only burn 4·52 kilos of coal, per hectolitre of juice, the boilers producing 9·88 kilos of steam per kilo of coal. The ammoniacal vapours passing into the serpentines of the heating apparatus do not cause any difficulty.

The objection might be raised to the above system that the high temperature in the first and second vessels might caramelise the sugar and colour the liquids, but very simple experiments prove that the syrups are coloured by a very high temperature only when they are highly concentrated, in the third vessel of the Triple Effet the concentration is done at a low temperature, whilst in

boiling to masse cuite, where the concentration is at its highest 3 to 4 atmospheres of pressure is used, thus it is in the boiling to masse cuite and not in the Triple Effet that the colouration takes place. Boiling to masse cuite by Double Effet at a low temperature is therefore necessary.

In conclusion, the manufacturer should use perfected boilers, or boilers with an apparatus for recovering the heat lost in the flues ; he should be clever in evaporating, having a triple or quadruple effet working correctly ; all the heatings should be done by multiple effets ; he ought also to use every means to prevent the loss of an atom of heat.

The advantage to a factory burning 100 kilos of coal per ton of beetroot should be 1 franc per sack of sugar and 1·50 and 1·80 respectively for factories consuming 150 and 180 kilos. of coal.

JARKOVSKY* entirely approves of the calculations and conclusions of Jelinek. He also recognises the merits of Rillieux, to whom many of the Austrian factories owe their rational triple effet apparatus, &c. The systems of Weibel - Piccard and Lexa - Rillieux also proved real progress.

The greatest importance must be attached to the production by the diffusion of juice as highly concentrated as possible. Further it is necessary to do away with all coarse muscovy, and to direct in a rational manner the cleanings of the filter presses and of the filters, and lastly to restrain the use of steam in the charcoal house.

The remainder of Jackovsky's article is a simple reproduction of a portion of Jelinek's work.

KRUGER (Stóbnitz) † pronounces himself in favour of Jelinek's system and apparatus. He condemns the use of the vertical apparatus for the third vessel of the Triple Effet, as the tubes are quickly corroded by the ammonia, which does not take place in horizontal apparatus. Tubes fitted in the latter 17 years ago are still in good condition, only their weight which was then 8 kilos is now reduced to $3\frac{1}{2}$ kilos.

NAGEL (Trotha) remarks that the tubes are not corroded in all factories working with sulphurous acid, because it developes itself in some cases from sulphate of ammonia.

* B. Z., vii., p. 342. † Z 33, p. 239.

The vertical system is useful for the first evaporating vessel, but detrimental to the others.

DRENCKMANN (Halle) considers that copper pipes *are less liable to be damaged than those of brass, but* Hahne formally challenges this opinion; he maintains the best means of preserving the tubes is to remove the *ammoniacal gases by some special arrangement.*

PASEL observes that the tubes are always destroyed in the centre.

EBERT states the curious fact that the tubes of the third vessel of the Triple Effet suffer the most, whilst the second vessel contains the most ammonia. The fact that the gases remain longer in contact with the tubes of vertical apparatus than with those of horizontal apparatus *sufficiently explains why vertical tubes suffer so much.* In the condenser where the vapour enters is always the most attacked by the action of the gas.

DR. JHLEE* (Trachenberg) insists on the great differences found in the working of evaporating apparatus. The heating surfaces necessary to evaporate the juice from 1,000 kilos of beetroot per day varies from 1 to 4 square metres.

B.—THE WELLNER-JELINEK SYSTEM.

Nearly all the old evaporating apparatus have the double disadvantage that the steam chamber, and the space for boiling the juice are very small, also the surface of the liquid, especially in vertical apparatus is insufficient. The result is that boiling takes place in a state of great violence, which causes loss produced by boiling over or by the vapour drawing away the liquid in a bladdery condition.

Vertical apparatus have at least this advantage, that their sides being perpendicular and the velocity of the vapour rising to the dome remains constant, which allows the heavy drops to fall back into the liquid. In horizontal apparatus, on the contrary, the discharge of the vapours from the liquid quickens more and more, according as they approach the dome, while the section of the discharge space lessens, and loss of juice becomes inevitable.

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* Z. 33, p. 617.

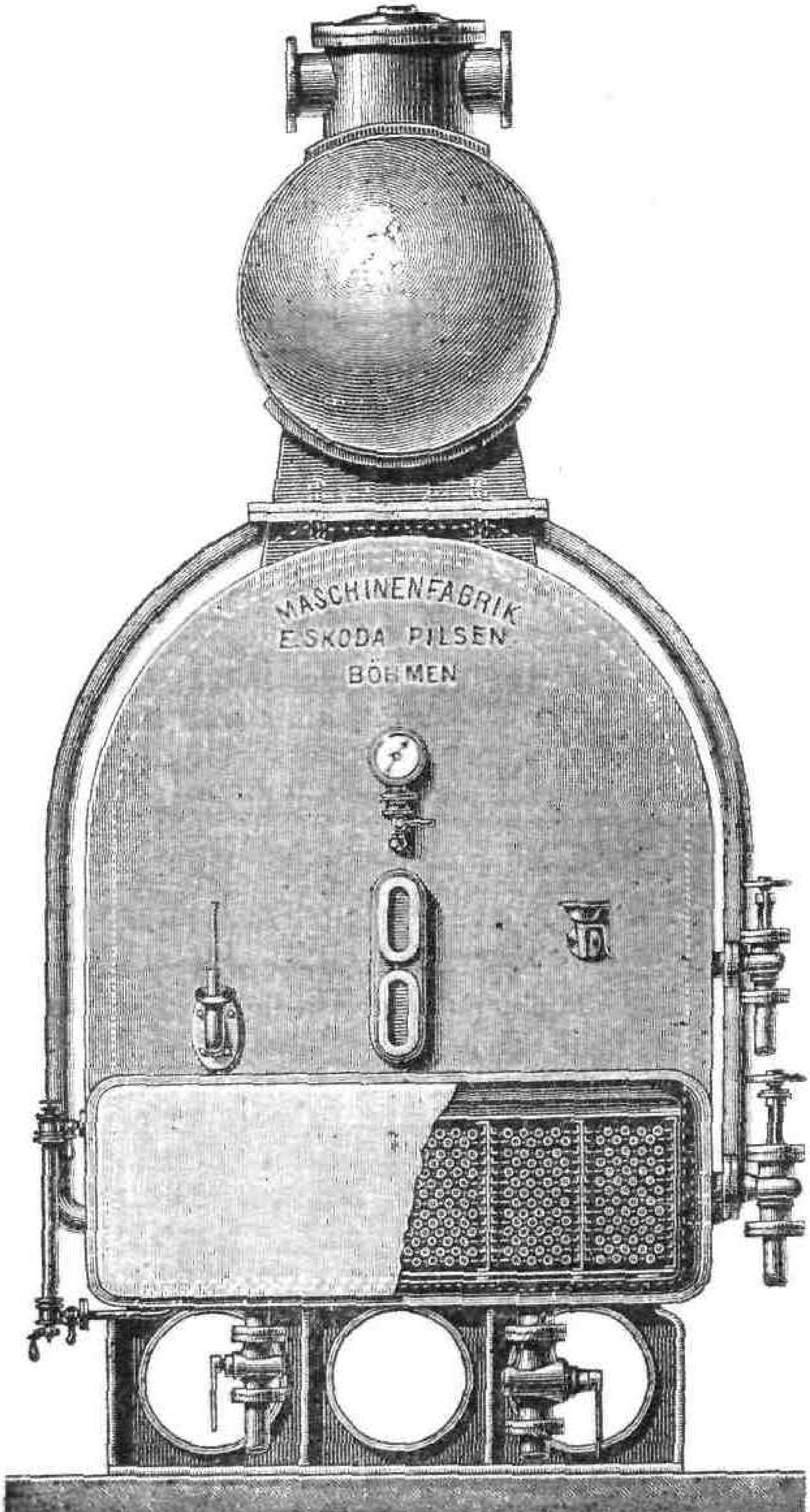

Fig. 76.

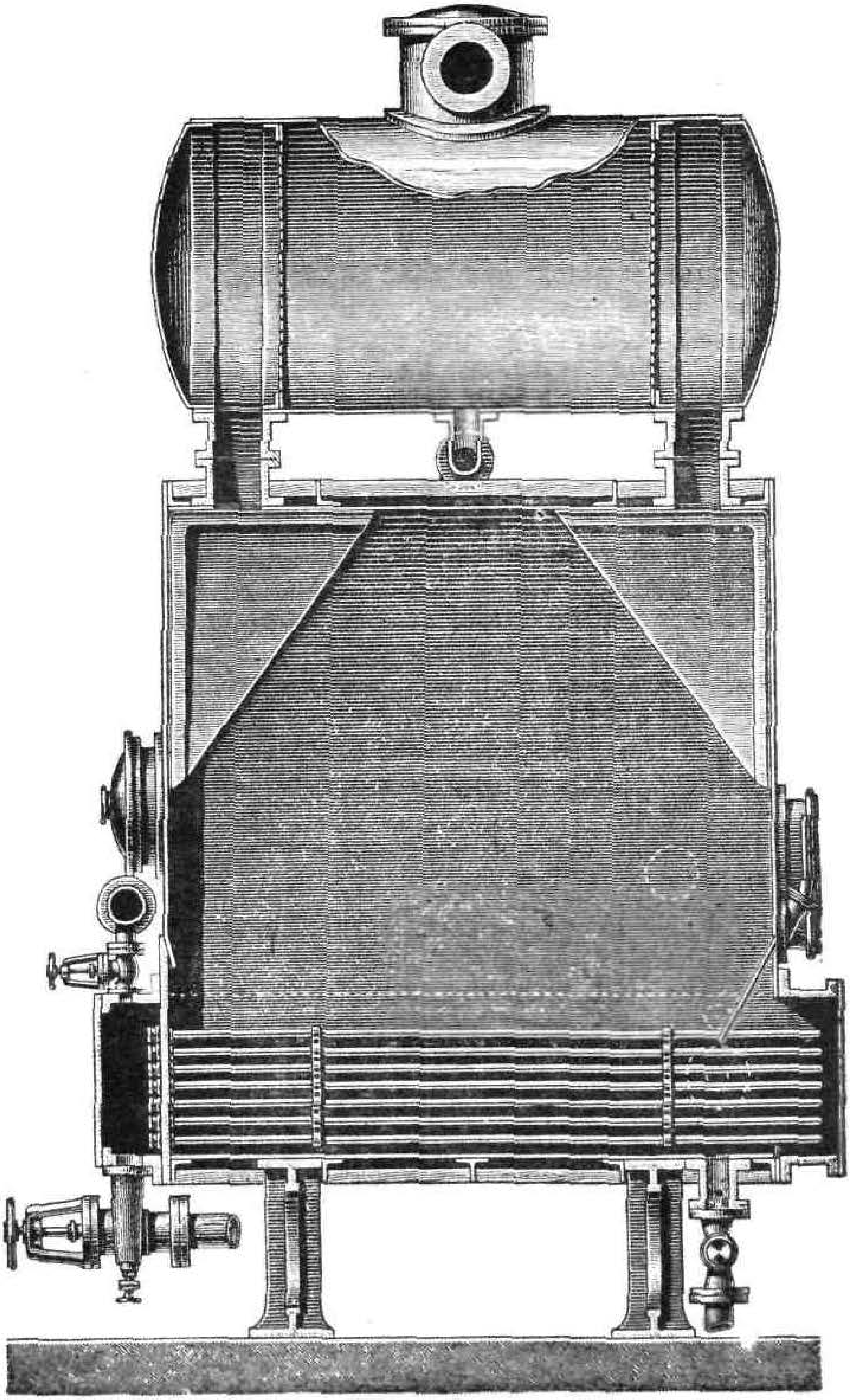

Fig. 77.

These are reasons which determined Hugo Jelinek (Prague)* to abandon the cylindrical form of the old apparatus and to substitute the rectangular prism surmounted by a half cylinder. Another drawback of the old form was the great height of the liquid, which often rose to 1·50 metres, and caused a notable diminution in the useful effect of the heating surface.

This is easily understood. Let us say we are going to evaporate water, and that a vacuum of 0·38 metres exists in the vessel, corresponding to 0·5 atmospheres, the result being that the upper parts of the liquid boil at 82° C, whilst the lower layers are exposed to a surplus pressure of 0·15 atmosphere corresponding to a height of liquid of 1·50 metres, thus we get a total pressure of $0·50 + 0·15 = 0·65$ atmosphere, corresponding to 88° C. The mean boiling temperature will thus be about 85° C.

Suppose now that the body of liquid has only a height of 0·50 metre. The liquid will boil at the surface at 82° C, as in the first case, and at the bottom at 84° C, corresponding to a pressure of $0·5 + 0·05 = 0·55$ atmosphere. The mean temperature will then be 83° C. We have thus gained 3° of temperature in the latter case compared with the former one. If we admit that the difference of temperature between two successive vessels of a Triple Effet be 30°, it will be seen that the useful effect of the heating surface is increased in the latter case 3°, or 10 %.

Jelinek likewise insists on the importance for the economical working of the apparatus, of the velocity of the vapour being always the same throughout the heating system as we have endeavoured to show in the general theory of evaporation.

These are the principles which have guided Wellner and Jelinek in the construction of their first evaporating apparatus, of which we give diagrams (figures 76 and 77).

The first thing noticed is the characteristic shape of this apparatus which can be well enough compared to that of a trunk. The height of the liquid in it is only 0·50 metre to 0·60 metre (0·75 metre according to Walkhoff) which suffices to completely cover the tubes or serpentines, which are only 20 millimetres diameter, and form the

* See pamphlet: Evaporating Apparatus and their Installation, by H. Jelinek. Page 109.

heating surface. The heating tubes are arranged in clusters, and the passage of the vapour is arranged in such a manner that the area of all the tubes which it passes through never exceeds the area of the pipe by which the vapour enters. Its velocity at the moment of entering the heating chamber, which is say 23 metres per second, remains the same until the moment of being discharged and is sufficiently strong to drive the condensed water from all the tubes.

In practice Jelinek's apparatus has transmitted 24 calories per minute per square metre of heating surface, for one degree centigrade difference of temperature, whilst ordinary vertical apparatus only transmit under these conditions 16 calories and horizontal apparatus still less.

The pipes communicating with the save-alls are throughout of large section, and the height of the evaporating chamber is 5 to 1 of that of the liquid. The liquid can thus never boil over, in spite of the rapid motion of the boiling. The apparatus is made stronger by inside ribs and belts outside, so as to be able to work under very high pressure.

LOUIS WALKHOFF (Kieff, Russia) whilst praising the great talent of Mr Jelinek, criticises the principal arrangements of this apparatus.

In the old Jelinek apparatus the heating systems are arranged horizontally alongside of each other, which retards the free flow of the condensed water. It would be preferable to allow the vapour to enter the upper tubes first and then descend successively into the lower ones, which would permit of the natural flow of the water.

Walkhoff then disputes Jelinek's opinion that the lower layers of a liquid are hotter than the upper ones, practical observations having demonstrated the opposite.

[We think it is possible to conciliate the contradictory opinions of Jelinek and Walkhoff on this point. Suppose we have to evaporate water, the upper layers of which are ready to boil at 82°, the vapour will heat the lower layers to a temperature which will not much exceed 82°, the pressure of the liquid having raised the boiling point of the lower layers, the liquid will not become boiling at this temperature, it will simply expand according to the laws of heat, and will rise towards the surface, where it immediately boils. If

the height of the liquid is great, this circulation of juice which is very favourable to evaporation, is impeded by the pressure of the liquid. We believe that Jelinek's opinion is open to argument, but that his practical conclusions are exact.—F.S.]

Walkhoff thinks that it would be necessary to take into account the contraction which is inevitable in tubes of so small diameter as Jelinek's, and that the economy realised by the use of these tubes will not be of much value to the sugar manufacturers who always pay for their apparatus according to their heating surface. Lastly the form appears to him too heavy,* and requires special strengthening pieces. He would prefer a horizontal cylinder of large diameter, which would offer many of the advantages claimed by Jelinek's apparatus, and which would offer more resistance.

BAUERMEISTER † says that he does not understand why, in the Jelinek system, the direct steam should follow the same course as the exhaust steam. If the pipes have sufficient length in the first case they will be too short in the second.

[We do not believe this criticism to be well founded, as it is evident that the effect of the apparatus does not depend only on the length but on the section of the heating chamber.—F.S.]

Wellner and Jelinek have since constructed a new evaporating apparatus, in which they have got over the principal difficulty mentioned by Walkoff, viz., the insufficient flow of the condensing waters.

Furthermore, this apparatus permits us to utilise for the evaporation of the juices, the exhaust and direct steam separately and at different pressures, which if combined would cause an increase in the back pressure on the engine. This arrangement of applying the steam is of great advantage when engines with a high grade of expansion are used, the introduction of which into sugar factories is so strongly recommended by Jelinek.

We here give diagrams of this new apparatus which has been called "The Evaporating Apparatus in Stages," (Fig. 78 to 81) of which a full description will be found on pages 118 to 122.

* Walkoff recalls that he constructed, in 1865, at Selichtchs (Russia), an Apparatus in the shape of a trunk, since which he has abandoned this shape.

† Z. 33, p. 667.

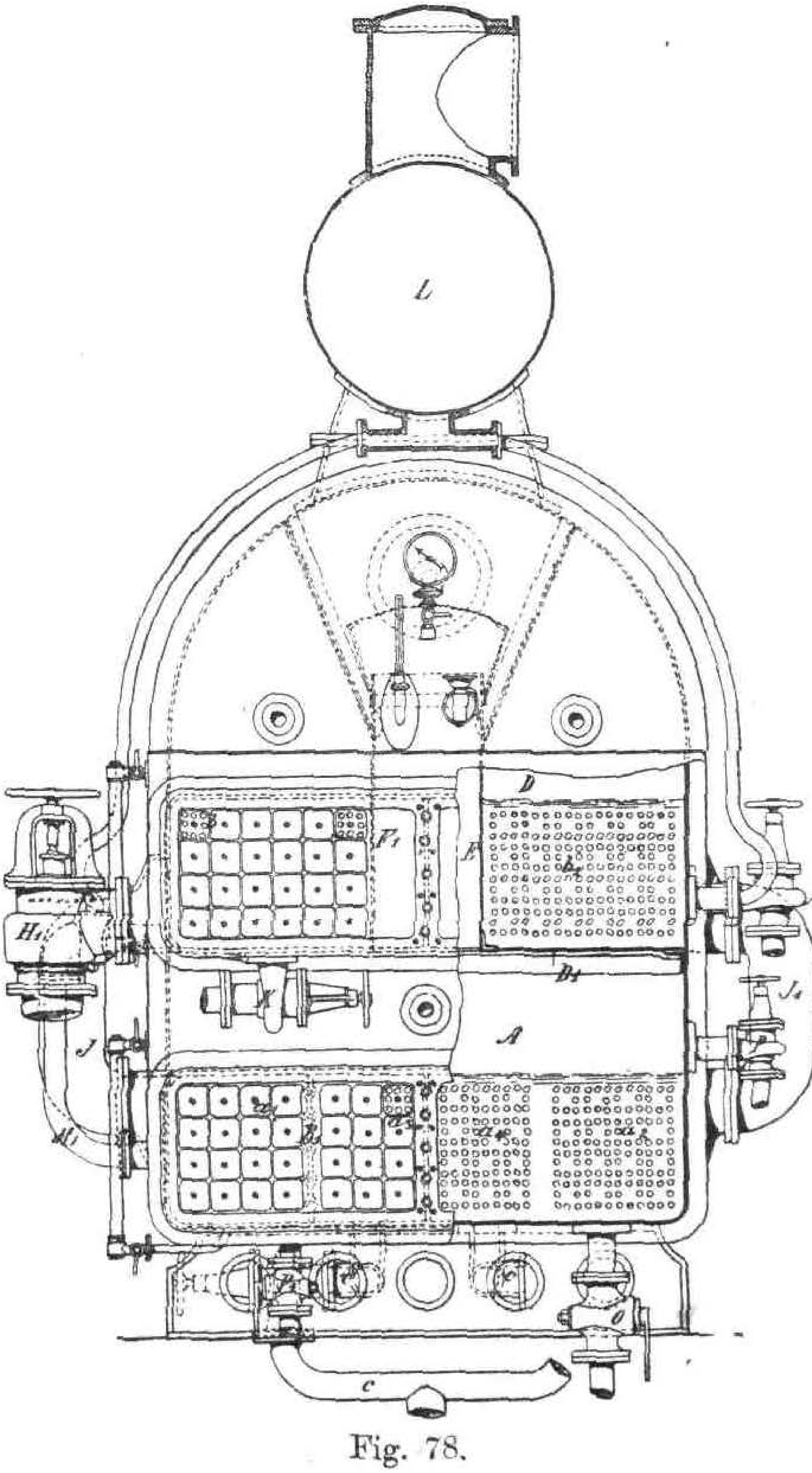

Fig. 78.

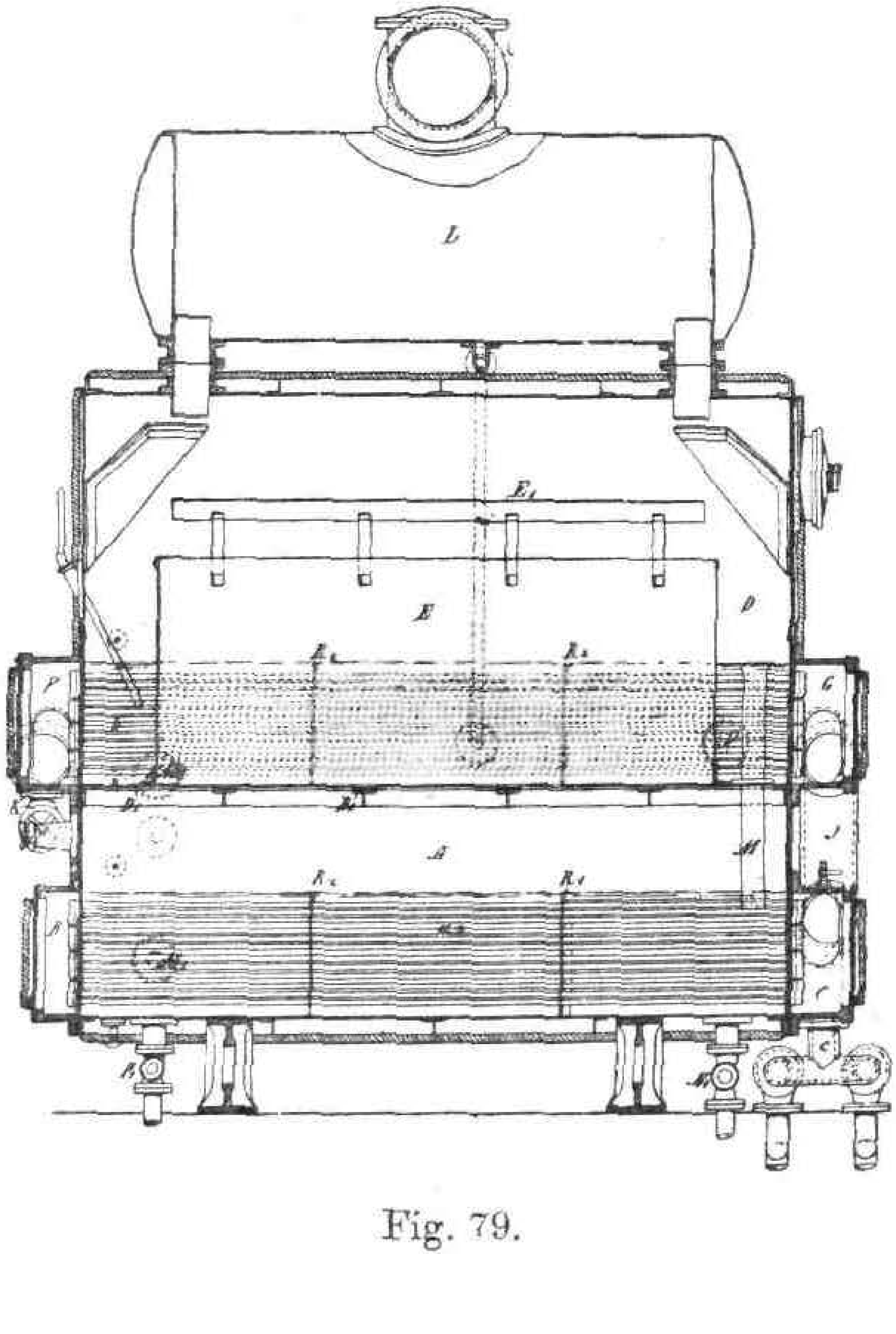

Fig. 79.

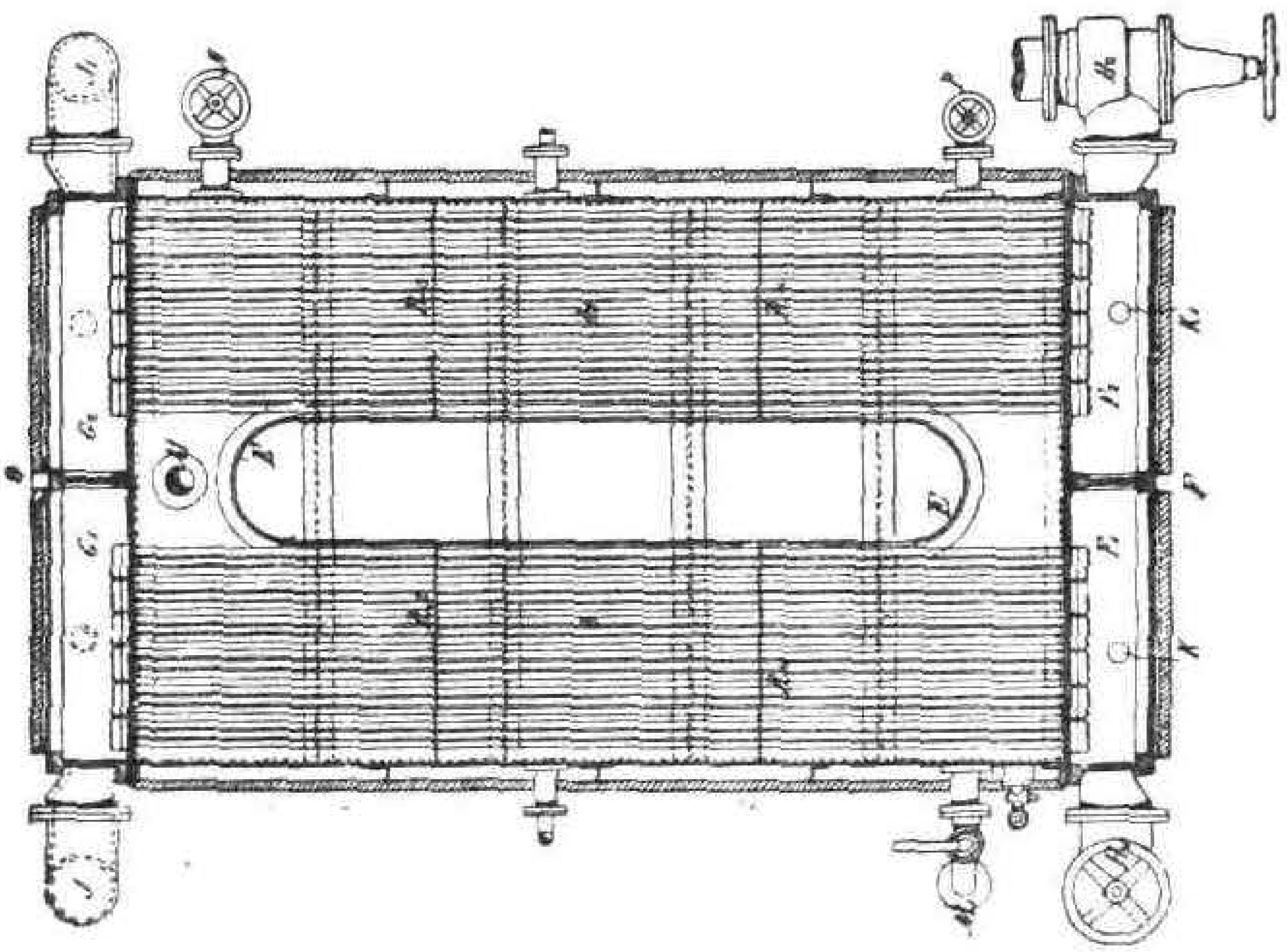

Fig. 81.

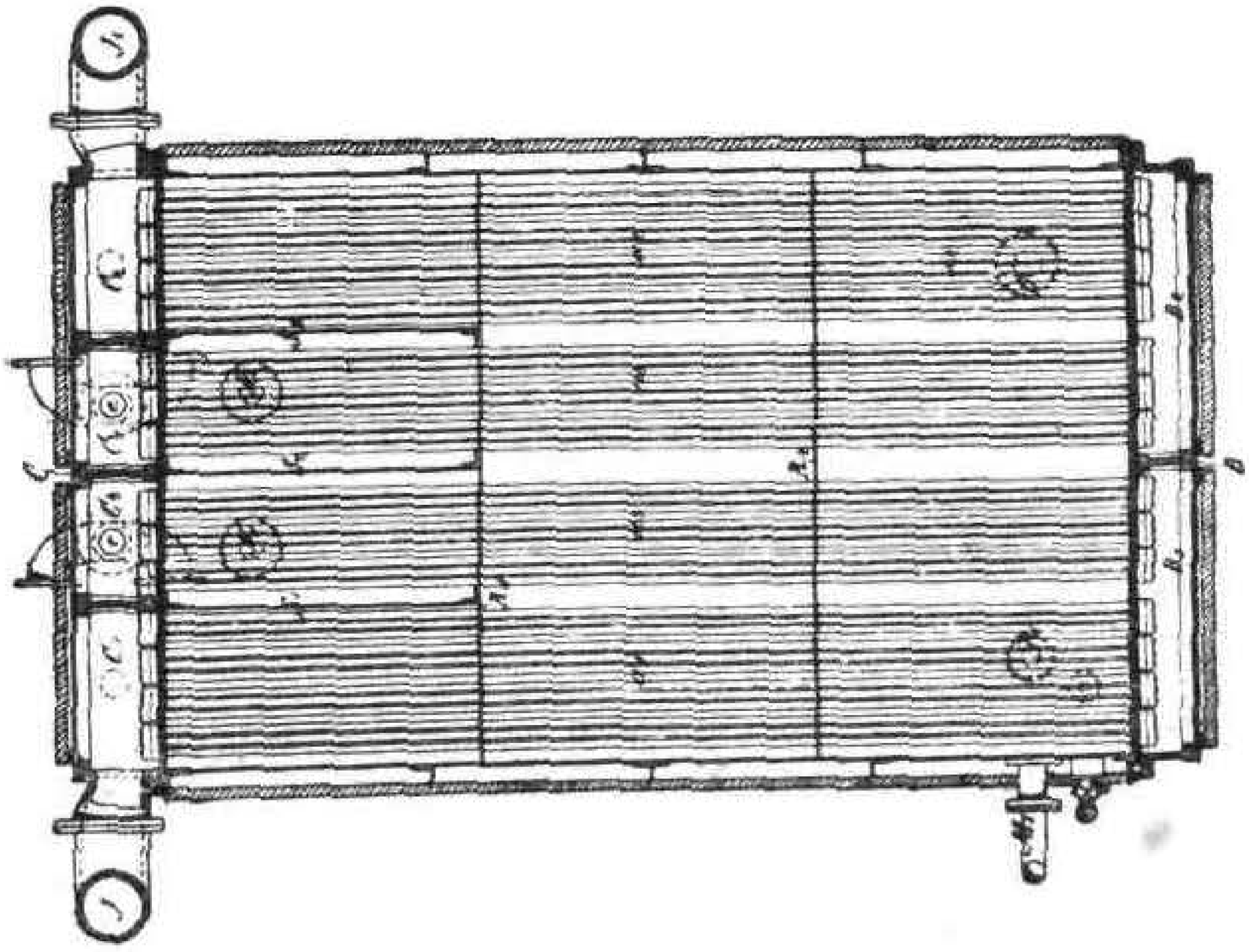

Fig. 80.